

**Inner 'Green' Space**  
A Study of Conservationism in Atrium Spaces  
Using Academic Buildings in Southern Ontario  
by

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A thesis  
presented to the University of Waterloo  
in the fulfillment of the  
thesis requirement for the degree of  
Master of Architecture



I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

A handwritten signature in black ink, appearing to read "BJS Smith". The signature is written in a cursive, flowing style with a large initial "B" and "S".





## Abstract

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Since taking hold in the mid 1960s, the modern atrium has become prevalent in many designs and buildings within contemporary architecture. The modern day atrium has endured to find its place amidst our current technologies and design aspirations by continuing to offer a capacity for assisting in urban strategies, providing strong economic returns on investment, conserving or recycling existing buildings, and for its potential to reduce energy consumption. Today, as concerns for energy and the environment rise to prominence within contemporary opinion, the reliance on more integrated conservational design strategies such as what the atrium offers in the matter of material and energy conservation is more relevant than ever. Yet simply including an atrium space within a building does not guarantee its effectiveness in realizing the potential for sustainable design.

By selecting to survey a collection of recently completed academic buildings in Southern Ontario, the thesis aimed to examine what current reality exists in our use of the atrium with regards to its conservational characteristics. By examining the atrium's ability to integrate sustainable design strategies in three areas: the adaptation into existing buildings and flexible program space; the use of effective daylighting; and the provisions to manage passive air handling; the thesis identified what conservational attributes are present and how often these functions are accomplished within the atrium designs of the selected study group of buildings.

Overall it was found that the current trends of conservationism in atria of the studied academic buildings are constant, that is, they do not exhibit growth proportional to the increasing awareness of 'green' and sustainable thinking seen in today's culture. Furthermore, the thesis closes with a concluding critique, providing a discussion surrounding the belief that though the atrium is a possible material and energy conservational tool, much of its success can be attributed to the meticulous planning and holistic approach involved in the execution of successfully resolved atria designs.



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Dedicated to the past 3 years,  
may they not be forgot even if they did past at the speed of light



## Table of Contents

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Abstract	iii
List of Tables	xiii
List of Photos + Illustrations	xv
Introduction	1
1.0 Part 1 :: Premise	7
1.1 Concept of the Modern Atrium	9
1.2 Classical Origins	12
1.3 Progression of the Modern Atrium	14
1.4 Identifying the Atrium Today	26
1.5 The Need for Conservationism	33
1.6 Atrium Characteristics of Conservation	37
2.0 Part 2 :: Atrium Investigation	49
2.1 Survey Preface	51
2.2 Survey Criteria Definitions	53
2.3 Academic Building Survey	57
3.0 Part 3 :: Results, Patterns + Trends	61
3.1 Overall Survey Results	63
3.2 Atrium Inclusion Results + Analysis	72
3.3 Atrium Reuse Results + Analysis	83
3.4 Atrium Daylighting Results + Analysis	91
3.5 Atrium Air Strategy Results + Analysis	97
3.6 Collective Analysis	103
Conclusions	109
Appendix A :: Building Case Studies	119
Appendix B :: Academic Building Catalogue	147
Appendix C :: Atrium Building Code	243
Appendix D :: Building and Air Relationships	251
Appendix E :: Designing for Air Movement	293
Bibliography	311





## List of Tables

---

Table 2.1	Buildings Completed in 2000 / compiled by author	58 - A
Table 2.2	Buildings Completed in 2001 / compiled by author	58 - B
Table 2.3	Buildings Completed in 2002 / compiled by author	58 - C
Table 2.4	Buildings Completed in 2003 / compiled by author	58 - D
Table 2.5	Buildings Completed in 2004 / compiled by author	58 - E
Table 2.6	Buildings Completed in 2005 / compiled by author	58 - F
Table 2.7	Buildings Completed in 2006 / compiled by author	58 - G
Table 2.8	Annual Totals Comparison / compiled by author	58 - H
Table 3.1	Self Proclaimed 'Green' Building / compiled by author	68
Table 3.2	'Green' Building Atria Characteristics Table / compiled by author	82
Table A.1	Case Study Comparison Chart / compiled by author	143
Table D.1	Minimum Ventilation Rates in Breathing Zone / Stien, 2006:1597	256
Table D.2	Minimum Ventilation Rates in Breathing Zone for Residential Buildings / ibid, 1600	259
Table D.3	Beaufort Wind Scale / Beaufort Wind Scale - <a href="http://www.spc.noaa.gov">www.spc.noaa.gov</a>	271



## List of Photos + Illustrations

---

Figure	1.01	Hyatt Regency: San Francisco, CA / <a href="http://www.flickr.com/">http://www.flickr.com/</a>	9
	1.02	BCE Place: Toronto, ON / <a href="http://wvs.topleftpixel.com">http://wvs.topleftpixel.com</a>	10
	1.03	Exeter Library: Exeter, NH / <a href="http://www.answers.com/topic/phillips-exeter-academy-library">http://www.answers.com/topic/phillips-exeter-academy-library</a>	11
	1.04	House of the Silver Wedding: Pompeii, Italy / <a href="http://www.indiana.edu/~class2/c102/net_id/images/">http://www.indiana.edu/~class2/c102/net_id/images/</a>	12
	1.05	House of Menander: Pompeii, Italy / Norberg-Schultz, 1985. p.104	12
	1.06	Ancient Greek House Floorplan / Cammesasca, 1971. p.46	13
	1.07	Developed Roman House floorplan / Cammesasca, 1971. p.53	13
	1.08	Sant' Ambrogio: Milan, Italy / photo by author	14
	1.09	San Clemente: Rome, Italy / <a href="http://www.sacred-destinations.com/italy/rome-san-clemente.htm">http://www.sacred-destinations.com/italy/rome-san-clemente.htm</a>	14
	1.10	Elevation, Crystal Palace: London, UK / <a href="http://en.wikipedia.org/wiki/The_Crystal_Palace">http://en.wikipedia.org/wiki/The_Crystal_Palace</a>	14
	1.11	Interior view, Reform Club: London, UK / Bednar, 1986. p.10	15
	1.12	Bon Marche: Paris, France / <a href="http://www.flickr.com/">http://www.flickr.com/</a>	15
	1.13	Rookery Building: Chicago, IL / <a href="http://www.emporis.com/">http://www.emporis.com/</a>	16
	1.14	Bradbury Building: Los Angeles, CA / Bednar, 1986. p.15	17
	1.15	Larkin Building: Buffalo, NY / Bednar, 1986. p.16	18
	1.16	Brown Palace: Denver, CO / <a href="http://www.brownpalace.com/press_room/photo_gallery.cfm">http://www.brownpalace.com/press_room/photo_gallery.cfm</a>	19
	1.17	Johnson Wax HQ: Racine, WI / Larkin, 1993: 56	21
	1.18	Marin County Civic Centre: San Rafael, CA / Levine, 1996: 42	21
	1.19	Guggenheim Museum: New York, NY / photo by author	22
	1.20a	Scarborough College: Toronto, ON / <a href="http://www.utsc.utoronto.ca/~advancement/greatminds/">http://www.utsc.utoronto.ca/~advancement/greatminds/</a>	23
	1.20b-c	Scarborough College: Toronto, ON / Canadian Architect, February 2004. p.18	23
	1.21	Place Alexis Nihon: Montreal, QC / photo by author	23
	1.22	Liverpool Civic Centre Proposal: Liverpool, UK / Saxon, 1983: 15	23
	1.23	Cambridge History Library: Cambridge, UK / <a href="http://www.hist.cam.ac.uk/library/seeleyphoto.html">http://www.hist.cam.ac.uk/library/seeleyphoto.html</a>	23
	1.24	Ford Foundation: New York, NY / Bednar, 1986. p.29	24
	1.25	Antoinette Graves houses: Atlanta, GA / Saxon, 1983. p.14	24
	1.26	Hyatt Regency: Atlanta, GA / <a href="http://www.flickr.com/photos/ryancramer">http://www.flickr.com/photos/ryancramer</a>	25
	1.27	Marriott Maquis: Atlanta, GA / <a href="http://www.flickr.com/">http://www.flickr.com/</a>	25
	1.28	Tokyo International Forum: Tokyo, Japan / <a href="http://www.cambridge2000.com/gallery/html/P71815325e.html">http://www.cambridge2000.com/gallery/html/P71815325e.html</a>	26
	1.29	Credit Valley Hospital Cancer Care Centre: Mississauga, ON / <a href="http://www.hospitalnews.com">www.hospitalnews.com</a>	27
	1.30	Thunder Bay Regional Health Sciences Centre: Thunder Bay, ON / Canadian Architect, February 2004: 22	27
	1.31	Technology Wing, Sir Sandford Fleming College: Peterborough, ON / photo by author	27

Figure	1.32	Beamish Munro Hall: Kingston, ON / photo by author	27
	1.33	High Park Lofts: Toronto, ON / photo by author	27
	1.34	Toronto reference Library: Toronto, ON / photo by author	27
	1.35	Toronto Eaton Centre: Toronto, ON / photo by author	28
	1.36	Queen's Quay Terminal: Toronto, ON / photo by author	28
	1.37	Montain Equipment Coop: Montreal, QC / <a href="http://greenbuilding.ca/iisbe/gbc2k5/teams/canada/MEC/can_MEC.htm">http://greenbuilding.ca/iisbe/gbc2k5/teams/canada/MEC/can_MEC.htm</a>	29
	1.38	York Computer Science Building [YCSB]: Toronto, ON / Canadian Architect, January 2001. 17	29
	1.39	Commerzbank Building: Hanover, Germany / Davis, 1997. 62	29
	1.40	Centre for Cellular and Biomolecular Research Building: Toronto, ON / Canadian Architect, January 2006. 33	29
	1.41	Swiss Re Building: London, UK / Architectural Record, June 2004. 223	29
	1.42	Closed Atrium / Saxon, 1983. 74	30
	1.43	One Sided Atrium / ibid, 74	30
	1.44	Two Sided Atrium / ibid, 74	30
	1.45	Three Sided Atrium / ibid, 74	30
	1.46	Linear Atrium / ibid, 74	30
	1.47	Bridging Atrium / Saxon, 1983. 75	31
	1.48	Podium Atrium / ibid, 75	31
	1.49	Multiple Vertical Atrium / ibid, 75	31
	1.50	Multiple Lateral Atrium / ibid, 75	31
	1.51	areial view, Los Angeles, CA / <a href="http://images.google.ca">http://images.google.ca</a>	33
	1.52	section, Genzyme Building: Boston, MA / <a href="http://www.behnisch.com">http://www.behnisch.com</a>	37
	1.53	University of Waterloo School of Architecture [UWSA]: Cambridge, ON / photo by author	38
	1.54	atrium, UWSA: Cambridge, ON / photo by author	38
	1.55	atrium used for assembly, UWSA: Cambridge, ON / photo by Bob McNair	39
	1.56	fritted glass, HP Science and Technology Centre [HP STC]: Toronto, ON / photo by author	41
	1.57	clerestory glazing, HP STC / photo by author	41
	1.58	HP STC: Toronto, ON / KPMB	42
	1.59	atrium, HP STC: Toronto, ON / photo by author	42
	1.60	solar chimney composite image, YCSB: Toronto, ON / compiled by author	43
	1.61	YCSB: Toronto, ON / photo by author	44
	1.62	atrium, YCSB: Toronto, ON / photo by author	44
	1.63	wall section, YCSB: Toronto, ON / photo by author	45
	2.01	atrium at the Schulich School of Business, York University, Toronto, ON / <a href="http://www.hariripontarini.com/">http://www.hariripontarini.com/</a>	51
	2.02	collage of academic buildings from thesis study / compiled by author	50

3.01	SCAET building: Sheridan College, Oakville, ON / photo by author	63
3.02	collage of atrium spaces found in the thesis study / compiled by author	62
3.03	central stepped atrium, Beamish Munro Hall, Queen's University: Kingston, ON/ photo by author	72
3.04	atrium, Davenport Chemical Research Building: Toronto, ON / photo by author	83
3.05	atrium, Lawrence National Centre for Policy and Management: London, ON / photo by author	83
3.06	atrium, University of Ontario Institute of Technology Science building / photo by author	88
3.07	atrium, Guelph-Humber building: Toronto, ON / photo by author	91
3.08	sun shade detail, Technology Wing, Sir Sandfor Fleming College: Peterborough, ON / Ferrara, 2006: 126	91
3.09	solar chimney at the Technology Wing, Sir Sandfor Fleming College: Peterborough, ON / Ferrara, 2006: 126	97
3.10	glazed atrium vent, YCSB: Toronto, ON / photo by author	100
3.11	atrium duct intake, School of Information Technology and Engineering: Ottawa, ON / photo by author	100

## APPENDIX A

Figure A.01	University of Waterloo School of Architecture [UWSA] Cambridge, ON/ photo by author	121
A.02	atrium, UWSA: Cambridge, ON / photo by Bob McNair	122
A.03	atrium, UWSA: Cambridge, ON / photo by Bob McNair	122
A.04	atrium, UWSA: Cambridge, ON/ photo by author	123
A.05	atrium, UWSA: Cambridge, ON/ photo by author	123
A.06	atrium, UWSA: Cambridge, ON/ photo by author	123
A.07	second floorplan, UWSA: Cambridge, ON / Levitt Goodman Architects	124
A.08	transverse section looking east, UWSA: Cambridge, ON / Levitt Goodman Architects	125
A.09	cross section looking north, UWSA / Levitt Goodman Architects	125
A.10	atrium, UWSA: Cambridge, ON / photo by Bob McNair	126
A.11	south facade, HP STC: Toronto, ON / KPMB Architects	127
A.12	eastern atrium, HP STC: Toronto, ON / photo by author	128
A.13	central atrium, HP STC: Toronto, ON / photo by author	129
A.14	atrium, HP STC: Toronto, ON / photo by author	129
A.15	central atria, HP STC: Toronto, ON / photo by author	129
A.16	level 2 Floorplan, HP STC: Toronto, ON / <a href="http://www.centennialcollege.ca/upload/File/Floor__Plan_HP_2nd.pdf">http://www.centennialcollege.ca/upload/File/Floor__Plan_HP_2nd.pdf</a>	130
A.17	cross section looking west, HP STC: Toronto, ON / KPMB Architects	131
A.18	cross section looking east, HP STC: Toronto, ON / KPMB Architects	131
A.19	transverse section looking southeast, HP STC: Toronto, ON / KPMB Architects	131
A.20	fritted glass detail, HP STC: Toronto, ON / photo by author	132
A.21	atrium clerestory, HP STC: Toronto, ON / photo by author	132

Figure A.22	[YCSB: Toronto, ON / photo by author	135
A.23	energy use comparison, YCSB vs MNECB Baseline / Canadian Architect, January 2001. 16.	135
A.24	composite image, YCSB solar chimney / photos by author	136
A.25	west atrium ceiling opening for solar chimney YCSB / Canadian Architect, January 2002. 18	136
A.26	east atrium, YCSB / photo by author	137
A.27	west atrium, YCSB / photo by author	137
A.28	west atrium, YCSB / photo by author	137
A.29	ground floorplan, YCSB / Busby Perking + Will Architects	138
A.30	schematic section winter/summer, YCSB / Canadian Architect, January 2001. 17	139
A.31	schematic section fall/spring, YCSB / Canadian Architect, January 2001. 17	139
A.32	cross section looking North, YCSB / Busby Pekins + Will Architects	139
A.33	transverse section looking West, YCSB / Busby Pekins + Will Architects	139
A.34	air passage / photo by author	140
A.35	vented wall partition/ photo by author	140
A.36	wall section / Nathaniel Lloyd	141

## APPENDIX B

All photographs have been produced by the author in  
Appendix B unless otherwise noted below.

Figure B.007i	exterior view University Plaza, Brock University: St. Catharines, ON / <a href="http://www.brocku.ca/facilitiesmgmt/CON_MAJOR_PLZ.htm">http://www.brocku.ca/facilitiesmgmt/CON_MAJOR_PLZ.htm</a>	154
B.008i	exterior view Minto Centre for Engineering Studies: Ottawa, ON / <a href="http://www.grcarchitects.com/portfolio.htm">http://www.grcarchitects.com/portfolio.htm</a>	155
B.014i	exterior view HP STC: Centennial College: Toronto, On / KPMB Architects	159
B.042i	Exterior view Heaslip House, Ryerson University: Toronto, ON / <a href="http://www.rdharch.com/education/continuing_education_ryerson/">http://www.rdharch.com/education/continuing_education_ryerson/</a>	183
B.057i	exterior view Access to Opportunities Program Building, University of Guelph: Guelph, ON / <a href="http://www.teeplearch.com/">http://www.teeplearch.com/</a>	198
B.061i	exterior view Science Complex Phase 1, University of Guelph: Guelph, ON <a href="http://www.uoguelph.ca/superbuild/science.shtml">http://www.uoguelph.ca/superbuild/science.shtml</a>	201
B.070ii	interior view of atrium: Bahen Centre, University of Toronto: Toronto, ON Canadian Architect, January 2003. 21	209
B.076i	exterior view Centre for Cellular and Biomolecular Research [CCBR], University of Toronto: Toronto, ON / <a href="http://www.greatspaces.utoronto.ca/">http://www.greatspaces.utoronto.ca/</a>	215
B.076ii	interior atrium view CCBR: Toronto ON / photo by Terri Meyer Boake	215
B.076iii	interior atrium view CCBR: Toronto ON / photo by Terri Meyer Boake	215
B.076iv	interior atrium view CCBR: Toronto ON / photo by Terri Meyer Boake	215
B.077i	exterior view, Communication, Culture & Information Technology Building, University of Toronto: Scarborough, ON / <a href="http://www.saucierperrotte.com/">http://www.saucierperrotte.com/</a>	216

B.100i	exterior view Schulich School of Business, York University: Toronto, ON / <a href="http://www.hariripontarini.com/">http://www.hariripontarini.com/</a>	237
B.100ii	exterior view Schulich School of Business, York University: Toronto, ON / <a href="http://www.hariripontarini.com/">http://www.hariripontarini.com/</a>	237
B.100iii	exterior view Schulich School of Business, York University: Toronto, ON / <a href="http://www.hariripontarini.com/">http://www.hariripontarini.com/</a>	237
B.102ii	double height dining room at the Executive Learning Centre, York University: Toronto, ON / <a href="http://www.hariripontarini.com/">http://www.hariripontarini.com/</a>	239

## APPENDIX C

Figure C.01-4	excerpts from the Ontario Building Code 1997 / 3-78 - 3-81	246-249
---------------	--	---------

## APPENDIX D

Figure D.01	open window / <a href="http://www.wikipedia.com">www.wikipedia.com</a>	253
D.02	psychosomatic chart / Lechnor, 2001: 61	261
D.03	psychosomatic chart, shifted comfort zone / <i>ibid</i> , 61	261
D.04	wind tunnel testing, Mercedes Benz E Class / <a href="http://www.rsportscars.com/foto/07/brabuse05_04.jpg">http://www.rsportscars.com/foto/07/brabuse05_04.jpg</a>	262
D.05	design proposal, Project WEB / Campbell, 2001: 5	262
D.06	Pearl River Tower, SOM Architects / <a href="http://images.businessweek.com/ss/06/06/som_skyscrapers/source/">http://images.businessweek.com/ss/06/06/som_skyscrapers/source/</a>	263
D.07	National Assembly of Wales, Richard Rogers Partnership / <a href="http://www.rsh-p.com/">http://www.rsh-p.com/</a>	263
D.08	Wind Cowl, National Assembly of Wales / <a href="http://www.rsh-p.com/">http://www.rsh-p.com/</a>	264
D.09	operable windows, Commerzbank Building / Davis, 1997: 85	266
D.10	sky atrium, Commerzbank Building / Davis, 1997: 36	266
D.11	four types of air flow / Lechnor, 2001:256	268
D.12	Bernoulli effect / <i>ibid</i> , 257	269
D.13	wind blowing trees / <a href="http://www.gettyimages.com">www.gettyimages.com</a>	270
D.14	effect of terrain on wind velocity profiles / Brown, 2001:17	272
D.15	wind patterns around single buildings / Stien, 2006: 71	274
D.16	the 'Bar' effect on a single building / <i>ibid</i> , 72	274
D.17	the 'Venturi' effect caused by two buildings / <i>ibid</i> , 72	274
D.18	the 'Gap' effect / <i>ibid</i> , 72	275
D.19	the 'Corner' effect / <i>ibid</i> , 72	275
D.20	the 'Wake' effect / <i>ibid</i> , 72	275
D.21	diagram, simple house layout / <a href="http://images.google.ca">http://images.google.ca</a>	276
D.22	window types with percentage operable area / Stien, 2006: 122	277
D.23	inlet and outlet sizes and air flow / Lechnor, 2001: 261	277
D.24	clerestory ventilation in double loaded corridor / <i>ibid</i> , 265	278
D.25	effective ventilation with an overhang / <i>ibid</i> , 261	278
D.26	roof ventilator designs and performance / <i>ibid</i> , 264	279
D.27	sketches, north american native people's tepee / compiled by author	279
D.28	Octagon House, axonometric / Banham, 1984: 37	283

D.29	Octagon House, section / <i>ibid</i> , 36	283
D.30	air diffuser / <a href="http://www.wikipedia.com">www.wikipedia.com</a>	285
D.31	simplified diagram, typical mechanical system / Allen, 1995: 85	285
D.32	displacement ventilation diagram / <a href="http://wbdg.org/design/minimize_consumption.php">http://wbdg.org/design/minimize_consumption.php</a>	286
D.33	prevalent wind ventilation design / Lechnor, 2001: 267	287
D.34	HVAC equipment / website unknown	288

## APPENDIX E

Figure	E.01	sand dune / <a href="http://www.gettyimages.com">www.gettyimages.com</a>	295
	E.02	paper strip and wood block modeling / photos by author	296
	E.03	paper strip and wood block modeling / photos by author	296
	E.04	paper strip and wood block modeling / photos by author	296
	E.05	dye flow in water flume / Van Dyke, 1982: 20	297
	E.06	air movement diagram / Brown, 2001: 185	297
	E.07	fabric installation / photo by author	298
	E.08	fabric installation / photo by author	298
	E.09	fabric installation / photo by author	298
	E.10	fabric installation / photo by author	298
	E.11	Smoke Box development / photo by author	299
	E.12	Smoke Box testing / photo by author	300
	E.13	Smoke Box testing / photo by author	301
	E.14	diagram, Smoke Box testing set-up / diagram by author	301
	E.15	Smoke Box examples / photos by author	301
	E.16	Swiss Re CFD modelling / <i>Architectural Journal</i> , April 2004: 65	302
	E.17	CFD Velocity Plots / Campbell, 2001: 18	303
	E.18	CFD model, auditorium of Experimental Media and Performing Arts Center at Rensselaer Polytechnic Institute: Troy, NY / <i>Metropolis</i> , March 2004: 104	303
	E.19	screenshot, AIOLOS Interface / compiled by author	304
	E.20	AIOLOS output for zone flow rate / compiled by author	304
	E.21	AIOLOS output for sizes / compiled by author	304
	E.22	wind tunnel, RWDI: Guelph, ON / photo by author	306
	E.23	air velocity visualization, RWDI: Guelph, ON / RWDI	306
	E.24	site model, RWDI: Guelph, ON / photo by author	307
	E.25	site model in wind tunnel, RWDI: Guelph, ON / photo by author	307
	E.26	water flume equipment, RWDI: Guelph, ON / RWDI	307
	E.27	building model, RWDI: Guelph, ON / photo by author	308







## Introduction

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The phenomenon of the modern atrium building can be traced back two hundred years to when glass and iron construction first became possible. Yet the atrium in itself is a very old idea. At the very least, the classical atrium has a three thousand year history as a grand entrance space, a focal courtyard and a semi-public sheltered area. Today the atrium space has evolved to find its place amongst our current technologies and design aspirations. This thesis intends to examine the modern day atrium amidst our most recent pressing design aspiration, the need for sustainable design.

It is throughout the latter half of the twentieth century that the modern atrium really took hold. Re-emerging in the late 1960's, principally in North America, the atrium was covered and conditioned providing public and private spaces on a grand scale. Initially these atria found a new hold in office buildings, grand hotels and shopping malls. As the resurgence propagated, the atrium space found its place in nearly all sectors of architecture, including health, education, and residential buildings.

The driving force for the atrium in the Western world was its feasibility through new building technology – technological advances which continually developed along with the atrium's proliferation. The attraction to the modern atrium was encouraged by its many faculties, of the most significant: the atrium's ability to assist in urban strategies, its strong economic ability to provide return on investment, its ability to help conserve or recycle existing buildings, and its potential to reduce building energy consumption.

It is a fact that over the course of the last forty years the atrium has proven its social, economic and technical feasibility to become a staple among building design. Thus, the future of atria in buildings seems to be assured.

Designing in the twenty-first century, some of our values and objectives are currently being redirected and refocused towards ideas of 'green', low impact and sustainable buildings. In light of this shift in design intentions, the atrium space has not faded from our design repertoire. In fact, it is well known that the atrium has much to offer in this area. What it offers is centered on the latter two aforementioned qualities: the atrium's ability to help conserve or recycle existing buildings, and the atrium's potential to reduce building energy consumption.

Material conservation is one avenue in the sustainable building discussion. The atrium promotes this cause by aiding in the adaptive reuse of existing buildings: old courtyard buildings can be covered into innovative atrium buildings; deep floor plate space can be hollowed out to include atria for useful shallower depths; extensions and renovations to existing buildings are linked by atria, preserving the old façades and mediating between old and new. By incorporating atria into such designs, it is possible to reduce the need for new construction and reuse existing buildings to tender new and exciting possibilities. Thereby the atrium is a tool for addressing low impact construction with adaptive reuse projects. Likewise, the space the atrium creates can be functionally dynamic. This offers a place within a building that has many uses, adding diversity to the building program and allowing the atrium to adapt to the changes the building has over time with changing owners, users and uses. Thus the atrium itself becomes a tool for adaptive reuse, which can prolong the life span of the building.

Energy conservation and reduction is the most prominent avenue of the sustainability discussion. The atrium facilitates conserving and reducing energy by working to assist the tempered indoor environment of the building. Depending on the design, the atrium can conserve energy in several ways: acting as an environment (climate) buffer between indoors and out; acting as a heat sink to store heat energy which is unwanted or stored until later needed; acting as a collection zone for expired air by being used as a bulk return air plenum. As a utility to the overall building, the atrium's transitional space can help conserve energy which the building utilizes to maintain itself. Likewise, if designed appropriately the atrium can reduce energy demands in one or more ways: brings daylight into the building to assist with electrical lighting; accumulates solar

radiation to gain passive solar energy either for winter gardens or precondition incoming air; generates air movement by providing interconnected vertical space, which facilitates air buoyancy (stack effect) to naturally cause air movement. The very nature of the atrium space – a large, open, multistory space with large portions of glazing – is what makes it such a useful tool. It allows the energy which is naturally present outside to come in and have an effect, while still maintaining a protective enclosure.

Over the years the atrium's strength has been its capacity for daylighting; nevertheless many projects have also been completed where atria act as passive energy sources, as places for heat storage and as ventilation chambers. The fact remains that the atrium's usefulness towards conservationism and in turn sustainability, is without question.

Simply including an atrium space within a building does not guarantee its effectiveness in achieving the potential of an atrium for sustainable design. This is only the case when designers have taken the time to design the atrium in a fashion which can facilitate the conserving benefits previously mentioned. Consequently, questions present themselves: What is the reality of our situation? What sustainable trends are present in atria designs? Furthermore, what sustainable atria strategies are being adopted and to what degree?

Based on the aforementioned facts (that atrium spaces are built as part of many buildings, and that those atria could assist sustainable designs) it is the goal of this thesis to identify what conservational attributes are present and how often these functions are accomplished with atrium elements, thereby determining trends currently employed in recently constructed atria.

The goals will be achieved by examining the atrium's ability to integrate sustainable design strategies through: adaptation into existing buildings and flexible program space, effective daylighting, and passive air handling. By first looking at each of these primary categories, characteristics are identified to outline how these atria are implemented, their effectiveness in contributing to a sustainable building and some examples of appropriate application. It is the strategy of the thesis to use this information on a selected group of recently completed buildings, in order to observe the occurrences of each category for analysis. Furthermore, a breakdown within each category offers the degree of use and usefulness for individual atrium characteristics. Through the gathered information this study will not only provide a critique of current trends of conservation and

atria, but will also provide speculation towards the strengthening of sustainability in atrium design.

With the vast number of new buildings built in our healthy Canadian economy since the start of the twenty first century, this survey of atrium buildings is not intended as an exhaustive report. Focusing in on a specific area of recent expansion and construction for its selected study group, the thesis used the resurgent growth in the post-secondary public institutions of southern Ontario, Canada. This study is only a sample of a select typology of architecture and can only offer limited speculation for atria in other situations and in other typologies. Further, this selection only addresses the buildings found in Southern Ontario and can only reflect this particular climate with its associated factors in accomplishing conserving and passive designs. Nevertheless this pool of projects provided a large number of new buildings which range from the most simple and modest to some very innovative and ambitious designs. Equally these projects have been designed by a broad range of architectural minds including architects from across the province, throughout the country and around the world. This diversity of project types and architectural styles both help offer a diverse study group.

The layout of this thesis is broken up into three parts in conjunction with an expounding appendix. The first part, Premise, offers a historical background of the atrium space and its development over the years. Rounding out the background information is a brief account of the ideologies of conservational and sustainable buildings and the relationship between buildings and energy consumption. The section is completed by bringing the two together and elaborating on the characteristics which the atrium offers to facilitate conservationism in the three categories described above: adaptation/reuse, daylighting and passive air handling. A fully documented building example for each category is found in the appendices.

The second part, Atrium Investigation, outlines the parameters used to arrive at the survey of recently completed buildings. Likewise, definitions of the criteria used on the survey are provided in combination with tables of the gathered data. The data shown in the tables is broken down annually and arranged by academic institution. A complete illustrated catalogue of the survey is found in the appendices.

The final part, Results, Patterns + Trends, offers the survey information in an organized, analytical and graphical fashion from which results and comparisons are laid out. Here the information is broken down into three tiers of results: the

overall survey, general atrium inclusion, and conservative atrium characteristics. The conservative atrium characteristics tier is further broken down into the three different aspects providing an individual section for each: adaptive reuse, daylighting and passive air strategies. Lastly a collective analysis is conducted bringing all three areas together to create an image of the conserving atrium characteristics' progression over time and their mutual relationships.

Amongst the results the acknowledgement of 18 specific buildings which consider themselves 'green' are highlighted as an internal comparison between ordinary and 'green' buildings. This sub group is outlined for contrast in each of the five sections.

Following the three parts of the thesis investigation, conclusions are offered from the results and comparisons. Hereby outlining the conservationism characteristics found in the atria of academic buildings in Southern Ontario post secondary institutions. With the notation of the found occurrences of each conserving characteristic, patterns of different breakdowns in atrium type, location and organizational use are expressed both as whole and in each area of atrium conservation. It is convincingly found that the current trends of conservationism in atrium of academic buildings is constant and does not reflect the growing awareness of 'green' and sustainable thinking seen in today's culture. Furthermore, through the conclusion discussion, the thesis provides a criticism surrounding the belief of the atrium as a straightforward conserving tool and proposes that much of its success is attributed to the meticulous planning and holistic approach to the atrium's design.





## **Part 1 :: Premise**

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## Concept of the Modern Atrium

## 1.1

The concept of the modern or 'new' atrium first developed in the early nineteenth century. The contemporary concept takes its roots from classical domestic Roman architecture, yet the modern atrium distinguishes itself by its "interiorness".<sup>1</sup> That is, it no longer remains open to the exterior, as in the Roman house, yet still maintains some manner of exterior connection (doors, windows, skylights). In the course of the modern atrium's conception and multiple revivals during the nineteenth and twentieth centuries, the atrium has become a space with a multitude of applications, forms and magnitudes across many different building typologies. The diversification in development has left little to definitively define the modern atrium. Nor has the term 'atrium' truly taken hold as a representative of its contemporary manifestation, adding to the ambiguity of the definition. For example, The Penguin Dictionary of Architecture still defines the atrium simply as:

"Roman domestic architecture, an inner court open to the sky and surrounded by the roof"

or

"Early Christian and medieval architecture, an open court in front of a church; usually a colonnaded quadrangle."<sup>2</sup>

Yet this in no way reflects the contemporary spaces referred to as atria. Furthermore the likelihood of this answer from any contemporary designer is doubtful. A recent internet 'Google' search for a definition of an atrium provided not only the above definitions but atop them all was:



fig. 1.01 - Hyatt Regency San Francisco, one of many Hyatt atrium hotels which helped establish the modern atrium in the mid twentieth century

“a usually skylighted central area, often containing plants, in some modern buildings, especially of a public or commercial nature.”<sup>3</sup>

From the people’s point of view, the Wikipedia site on the internet offers the following as the opening definition of an atrium,

“a large open space, often several stories high and having a glazed roof and/or large windows, often situated within an office building and usually located immediately beyond the main entrance doors.”<sup>4</sup>

It seems the more contemporary the source, the more relevant the definition to the atrium’s contemporary form. Furthermore the term encompasses many different manifestations which have resulted in the modern atrium better described as a concept, rather than a definitive form. To arrive at a working definition of the modern atrium concept, we can combine a typical contemporary description with the research of Richard Saxon and Michael Bednar, both whom are established authors on the study of the modern atrium. We will begin by using the Wikipedia description above as a typical illustration of the modern day atrium. It simply describes an atrium space and its basic physical characteristics, but we will omit the notion of solely being located in office buildings, as atria are found in all uses of buildings. From here we will combine this illustration with Richard Saxon’s idea of atrium as destination and Michael Bednar’s ideas of atrium for orientation and spatial organization.

Richard Saxon, who wrote and compiled Atrium Buildings: Development and Design in the early nineteen-eighties, and a follow up book, The Atrium Comes of Age, a decade later, has followed the developments of the modern atrium. Saxon defines the concept of modern atria in his first book as “static, arrival spaces, with if anything, a vertical emphasis;”<sup>5</sup> He chooses this definition in an attempt to distinguish the modern atrium from similar architectural spaces such as galleries, arcades and winter gardens. All which have similar elements, interior verticality with a significant portion of glazing, yet do not extend themselves to the same idea of destination. His singling out of the atrium space as being one of destination, is key in understanding the concept of the atrium in today’s architecture. Most often the space called ‘atrium’ is an intermediate or resting destination which encompasses a rising vertical space connecting the building both horizontally and



fig. 1.02 - Toronto’s BCE Place atrium by Santiago Calatrava; preserves historical façades within while offering an awe inspiring architectural space

vertically. The atrium is not a final destination yet a temporary one for further organizing or gathering, and orienting oneself to connect with the rest of the building. This leads us to Bednar's definition.

Michael Bednar, who wrote The New Atrium, also in the nineteen-eighties, takes a more practical approach and defines the modern atrium as "a centroidal, interior, daylit space which organizes a building...it serves as a place of orientation for the rooms which surround it, thereby bringing spatial coherence to the building."<sup>6</sup> In the eyes of Bednar, the atrium is a functional space for bringing the building together, both orderly and spatially. This is true in most cases of today's atrium, where atria are often part of lobbies, or hubs within a building which are ideal for organizing, connecting and routing building circulation. Likewise, the verticality of the atrium ties the building together spatially, bringing multiple levels together through the atrium opening, either physically by stairs or visually by providing views with glazed partitions.

Accordingly, the concept of the modern atrium is a synthesis of the three. It consists of large open multistory spaces with visual and sometimes direct connection to the exterior, such as windows, skylights and doors. And the modern atrium is an internal volume which serves as a place of spatial destination, orientation and building organization. Nevertheless, the atrium is a changing and evolving architectural design element. As atrium design progresses with contemporary architecture, this term is now used to refer to a varying use, form, and appearance to encompass a variety of spaces. Much of the ambiguity and discrepancy is a result of the development over the course of time. To have a better understanding of these developments before going into the thesis survey and analysis, a brief historical development will be examined.



fig. 1.03 - The atrium at Louis Kahn's renowned Exeter Library

## 1.2

## Classical Origins



fig. 1.04 - Roman House tetrastyle atrium as seen in the House of the Silver Wedding amongst the ruins of Pompeii



fig. 1.05 - Typical example of a domestic Roman atrium in the Tuscan Style at the House of Menander in Pompeii

The atrium building as a spatial type did not truly emerge until the nineteenth century. However its historical predecessors can be found in architecture since the beginning of recorded history. Perhaps ironically, the atrium was founded on the many uses we now term 'green' and sustainable.

### Origins of the Classical Atrium

The atrium originates in domestic architecture which came about with the development of early cities. The reality of close proximities in the newly emerging urbanism brought about new conditions: a lack of privacy, limited land area, and limited exposure to communal space. The atrium plan was a logical solution to these conditions while providing positive amenities which dealt with basic climatic control. The very form of the atrium was able to be a source of natural light and air, protection against the winds, a private outdoor space, a heat sink in the winter, and a place of shade for coolness in the summer.

Our only window into most of the architecture of the past is through archaeological exploration. The earliest found example of a courtyard house was in Ur on the Euphrates River in Mesopotamia, dating from the third millennium B.C. In this layout all rooms are organized around a centrally placed courtyard, with each room opening onto it. This is the earliest known precursor to the domestic atrium.<sup>7</sup>

The next significant development is accredited to the Greeks. In the Fifth Century they began to enlarge and develop the courtyard house. Here the courtyard was surrounded by columns forming a peristyle. See fig. 1.06 for a plan of the ancient Greek house. The peristyle formalized the courtyard while forming a circulation zone around the courtyard. As a result the rooms of the house relate to the courtyard only indirectly due to the intervening circulation.<sup>8</sup>

The true classical concept of the atrium best comes from the Romans, which dates back from the third century B.C. However, the Romans may have actually borrowed the atrium concept from the conquered Etruscans, who used it prior to the Romans as early as the sixth century B.C.<sup>9</sup> Nevertheless the abundance of Roman atrium examples has not only been found through many excavations, but also in the writings of Vitruvius and his Ten Books on Architecture, thereby providing the image for the classical atrium. In his writings, Vitruvius refers to the atrium as a cavaedium, that being the closed-in court nearest



the entrance. In Chapter III of Book VI he offers five different styles of the cavaedium (atrium):<sup>10</sup>

*Tuscan* – the atrium roof is supported by girders and crossbeams which run the full width of the atrium. The roof is sloped inward toward the central opening (compluvium) so that rain water can be collected in the cistern. See fig. 1.05

*Corinthian* – same construction and form as the Tuscan except that the roof is supported on columns all around the roof opening which forms a peristyle.

*Tetrastyle* – same construction and form as the Corinthian, except that only four columns are used, one at each corner of the roof opening.

*Displuviat* – the atrium roof slopes away from the central opening, forcing the rain of the sides. This setup provides a higher roof allowing more light to be brought in.

*Testudinate* – this setup is used in two-storey houses, usually with short spans where the atrium was completely roofed over.

In early times the atrium's centre held a cooking hearth, most likely to exhaust air from cooking and the cooking fire. After the 2nd century B.C., when the hearth was placed elsewhere, the centre of the atrium held a tank (impluvium) to receive rainwater falling through the opening, for cooling, washing, or other household uses. The atrium space was seen primarily as a pragmatic element, used to exhaust, light, and capture water. Depending on the scale and overall layout of the residence, the atrium was also often used as a semi-public reception hall to entertain guests.<sup>11</sup> From the ruins of Pompeii and Herculaneum excavations, atria in their various forms have been documented; see fig. 1.04 for an image of the domestic Roman atrium found in the well known House of the Silver Wedding, amongst the excavated ruins.

In the completely developed Roman house, the Tuscan atrium was joined with the Greek peristyle in the same plan. See fig. 1.07 for a floor plan. The atrium was at the front of the house, joined to the street by a vestibule. The atrium became the public part of the house, surrounded by rooms which were used for shops or offices. In the rear of the house, joined with the atrium through the living room, was the peristyle courtyard.

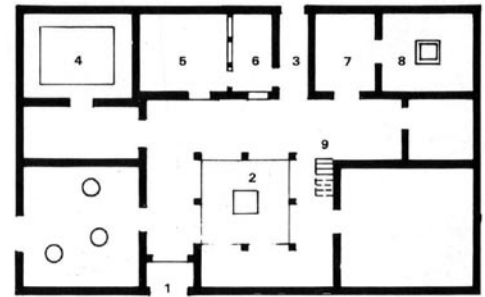


fig. 1.06 - Ancient Greek House floor plan;  
(2 - atrium)

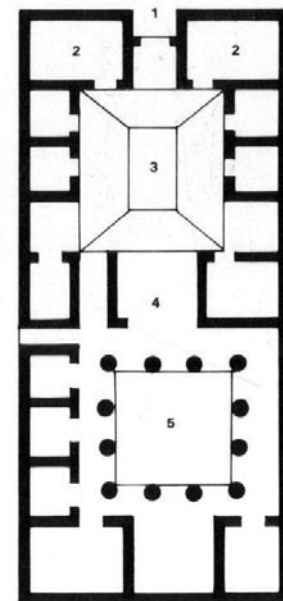


fig. 1.07 - Developed Roman House floor plan,  
showing joined (3) Tuscan atrium and (5)  
Greek Peristyle atrium (or Roman courtyard)



fig. 1.08 - The atrium seen in Early Christian churches at Sant' Ambrogio in Milan Italy



fig. 1.09 - Early Christian atrium at the Church of San Clemente in Rome Italy

It was around the courtyard where the private or familial functions took place. Thereby, the atrium became the primary communal space in a plan to which all secondary spaces are related such that they have direct visual and physical access. The atrium centric Roman house plan continued to be used until the third century A.D.<sup>12</sup>

In the subsequent period of architectural history extending until the eleventh century, the term atrium was used to refer to the space in front of the entrance to a Christian Basilica. In this application of the term, the atrium was a large arcaded or colonnaded open court, serving as a general meeting place, in front of the church itself, often with a fountain in its centre.<sup>13</sup> The basilican churches of Sant' Ambrogio in Milan and San Clemente in Rome still have noteworthy examples, see fig. 1.08 + 1.09. However as this application of the term atrium is not true to the form of the classical atrium, some historical confusion has set in creating ambiguity of the term. Eventually the term cloister replaced this application of the term atrium, and is the present day accepted terminology.

Furthermore, the distinction between a Roman atrium and a court over the course of history has added to the confusion of the term atrium. The difference to be made between the two is in the degree of relationship between the atrium or court space and the surrounding rooms. In a court there is a greater restriction in physical and visual access than that of an atrium.<sup>14</sup> Nevertheless the historical court has also offered a formal model to the development of modern day buildings and atrium spaces. However, it was not until the success of glass and iron technology in the nineteenth century, did the atrium re-emerge as a permanent feature in architectural design.

## 1.3

### Progression of the Modern Atrium

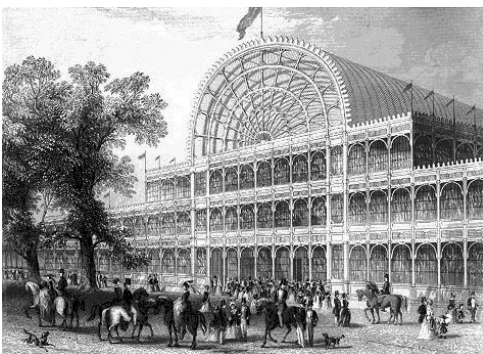


fig. 1.10 - The Crystal Palace, Joseph Paxton's apex of metal and glass buildings in the 19th Century

Over the course of history, the term atrium has not always referred to a consistent architectural form. Beginning in the nineteenth century, our present day atrium was developed; the metal and glass enclosed spatial volume, distinguishing itself from the wood and masonry open-air Roman atrium of antiquity. Different eras of the modern atrium's development and proliferation, between the nineteenth century and first half of the twentieth century, have been identified by Richard Saxon in *Atrium Buildings: Development and Design*,<sup>15</sup> and similarly by Michael Bednar, in *The New Atrium*.<sup>16</sup> Based on their two accounts, three specific eras will be used to outline the accomplishment and success of the modern atrium



## First Signs of the Modern Atrium

At the start of the nineteenth century metal and glass became frequently used as significant architectural components. Cast iron and wrought iron had been available for some time, yet it was the development of steel, which could span greater structural distances and permitted steel to take hold in the nineteenth century. Much of this new found strength in steel resulted from new steel manufacturing processes in France, England and America, such as the Bessemer method developed by Sir Henry Bessemer in the mid 1800s. Concurrently these developments were coupled with developments in glass manufacturing, which resulted in the production of larger panes. These two new developments combined to allow large pieces of glass which could be held in place with milled-iron frames and supported over greater spans than ever before.<sup>17</sup>

The attraction to this new technology led to the creation of entirely new architecture: buildings completely made of steel and glass. Stemming from uses for greenhouses and galleries and moving on to train stations, exhibition halls and markets, the new glass and iron building type culminated in Joseph Paxton's Crystal Palace (fig. 1.10), built at Hyde Park, in London, England. An architectural space of unprecedented scale, at 560 meters long, 140 meters wide and 33 meters tall, the building was completely transparent with glass and composed entirely of iron structural members.<sup>18</sup> Concurrent with the evolution of the all glass and iron buildings, this new technology was used in combination with traditional masonry buildings. Here two new modern iterations were formed: the arcade and the atrium. In these buildings traditional masonry was used for the vertical structure and enclosure, while iron and glass were used to frame a sky-lit roof. The arcade is a glass covered passageway lined with shops which connects two busy streets, while the atrium is an internal destination, with wider functional applications.

Although there were many precursors to the atrium building, the first identified modern atrium was in the Reform Club (1837- 1841) by Sir Charles Barry in London, England. Using the court of the Pallazzo Farnese (Rome, Italy) as his inspiration, Sir Charles Barry took the next historical step and roofed it over with a vaulted metal structure infilled with glass, see fig. 1.11. He thereby created an interior court which took advantage of natural daylight yet still offered protection from the elements. Of the many atrium buildings built during this time, other notable English examples are the Bridgewater House, also by Sir Charles Barry; and the London Coal Exchange, on Lower Thames Street also in London by J. B. Bunning.



fig. 1.11 - One of the first true examples of the modern atria at The Reform Club in London, England



fig. 1.12 - Contemporary photo of the atrium at the Bon Marché, which still exists in Paris, France

Similar buildings were showing up in France at this time, as many atria were built as part of large department stores and markets. The French called them 'galleries', and in Paris, at least 39 of these were built between 1843 and 1879. The Bon Marché (fig. 1.12) of 1876 by Boileau and Eiffel is one of the best-known examples. Yet the French did not stop there as they began to exploit the atrium space for other building types, such as hotels, offices, museums, apartments and libraries. The French thereby demonstrated the atrium's diverse feasibility by using its many functional applications.<sup>19</sup>

Consequently, it can be said that the first epoch of the modern atrium occurred during the nineteenth century within England and France. Here the modern atrium was first invented and explored as a spatial type. Yet excitement with the new rendition of the atrium wore off toward the end of the century in Europe, with changing architectural styles and forms. Adding to this decline was the emerging awareness of the fire hazard which came with steel and glass technologies. It was found, as many of these buildings burned and collapsed, that both glass and steel offered very little durability in the intense heat of building fires.



fig. 1.13 - The lobby atrium of the Rookery Building in Chicago

#### The Second Coming of the Modern Atrium

At the same time atrium designs died down in Europe, they began to show up for the first time in America. Just before the turn of the twentieth century, America began seeing the construction of buildings using masonry on the exterior, with iron, steel and glass used sparingly for interior atrium spaces. Most likely this conservative approach was a response to the fire hazards seen in European steel and glass buildings. It was during this period that a number of atrium uses and characteristics came into full realisation. The possibilities of low energy design with atria were developed; the usefulness of the atrium space to accommodate buildings which had to deal with many people at once; and the creation of many well known predecessors of atria for the twenty first century. It was then that America saw the emergence of unofficial guidelines for the typical atrium office building, the appearance of atria within department stores and museums, and the first example of an atrium hotel.

One of the most established atrium designers during this period was the Burnham and Root firm and its subsequent incarnation, D.H. Burnham and Company, both of Chicago. Between 1882 and 1905, at least eleven major atrium buildings were designed and completed by this architectural firm. As a collection, these buildings represent significant advancement in

the concurrent developments of the high-rise building with steel structural frame, passenger elevators, and the light court and/or atrium. In these instances, atria served as public lobbies and circulation centres which featured elevator banks and centrally located grand staircases. The lower floors connecting to these atria usually maintained shops and offices which served the public, who thus benefited from the civic connection created by the atrium. Overall it was the desire for natural light and air which motivated these building forms. Clients found the sacrifice of additional office space was outweighed by the desire to bring natural light into the offices.<sup>20</sup>

The most significant of the Burnham Company buildings is the Rookery in Chicago, completed 1885. The Rookery distinguished itself both in its steel skeleton construction and the grandeur of its atrium which are part of its ten story light court rising full height in the centre of the building. The bottom two storeys are glazed over with detailed steel work and glass to form the atrium which contains the grand lobby with sculptural stairs and public shops. The main stair connects to the second floor promenade which encircles the atrium to meet up with a cantilevered iron stair and ascends into an oriel stair rising the remaining building height above the atrium. See fig. 1.13. An elegant gesture, the Rookery Building is one of many to find the atrium and/or light court useful for placing the building's vertical circulation routes. Furthermore, it is among the earliest examples where office views into the light court are seen to be as desirable as those which face the street, as the inner offices not only received daylight but could enjoy the activity within the atrium by looking down through its glass ceiling.<sup>21</sup>

The Bradbury Building in Los Angeles, designed by George Wyman in 1893, can be seen as a model for many present day atrium plan office buildings. The atrium serves as a magnificent interior lobby, with a pedestrian scale, to which each of the tenants is directly related. Five levels of offices surround the atrium, with each office entrance opening onto a gallery which circles the 15 meter by 36 meter atrium. See fig. 1.14. Amidst the atrium are multiple stairways and elevators, which use the open interconnected space to fully accommodate vertical circulation. The Bradbury Building was also one of many buildings at the time which used its atrium for low energy design. The clear glass skylight provides abundant daylight for the interior during the daytime. As electricity had not yet become pervasive in domestic use, gas lamps were installed for lighting and fireplaces or stoves were used around the perimeter yielding the minimal heating required in the mild Los Angeles climate. The required fresh air for these amenities was



fig. 1.14 - Atrium view inside the Bradbury Building

designed to enter through exterior windows and flow onward through door transoms. Pivoted windows, at the top of the wall just below the atrium skylight, served as outlets for exhaust venting.<sup>22</sup> The Bradbury Building design optimizes the atrium's low energy practicality, by working to provide air movement along with natural daylighting.

Office buildings which had semi-public or private atria were also built where there was only a single tenant in the building. Frank Lloyd Wright's Larkin Building (fig 1.15) completed in Buffalo in 1904, (demolished in 1950) is an example of such an atrium building. Here the floor of the atrium was used as a work space overlooked by five levels of offices, thereby connecting the entire office together. The skylights over the atrium brought daylight into both the atrium workspace and the surrounding offices on all five floors. This integrated single interior volume would later be seen in contemporary smaller buildings with atria as well as contemporary single tenant office buildings.



fig. 1.15 - The Larkin Building atrium used as a work space due to its single tenant occupancy

Another strand of atrium development occurred in the American hotel. The two came together for the very first time in 1892, when the Brown Palace (fig. 1.16) opened in Denver, Colorado. The design of Chicago based architect Frank Edbrooke, the Brown Palace was the first hotel ever designed with an atrium in its centre – unique then and precedent setting for many more to come in the mid twentieth century. The hotel itself is built on a triangular lot, resulting in a triangular building with an odd trapezoidal atrium inside. Nevertheless, nothing is lost in the effect of the atrium as it expands upwards ten storeys, covered by a double domed skylight with patterned and coloured glass. A wrought-iron balustrade gallery surrounds the atrium on each floor, giving access to guest rooms, while allowing visual connection throughout the hotel. On the ground floor the atrium serves as the main lobby and directly links to the main entry and other hotel services, again allowing the atrium space to tie the whole hotel together. Also of significant note, the Brown Palace was only the second American building to be fireproofed. The partitions and floors were made of terra cotta and an exterior of brown sandstone and red granite covers the steel frame construction, providing a defence against the quickly destructive effects of fires on steel buildings.

At this time, America also saw its first atria placed in department stores following the earlier French tradition. The Marshall Field Store in Chicago and the John Wanamaker's Department Store in Philadelphia are two worth noting. The atria themselves were modest but very effective in their setting due to the point of orientation and spatial relief they provided.



Although this typological use was only in its infancy many more and much grander atria would follow these precedents later, in the middle of the century.<sup>23</sup>

Monumental civic architecture was also not to be left out, as the atrium was often included when constructing such buildings as post offices, courthouses and city halls. These applications were first seen at the turn of the century in America, and were used to address the space needed to accommodate buildings dealing with many people at once. Many of these buildings have survived to the present day, yet have been renovated to suit new and changing uses.<sup>24</sup> Among civic buildings, the first museum with an atrium stood out as a provocative pairing. It was the Gardner Museum in Boston which served as a precedent for many subsequent museums to incorporate sky lit courtyards for displays, gardens, and/or places of repose.<sup>25</sup> Again it did not flourish right away, but the atrium space and museums would come together later mid-century.

The second epoch of the modern atrium lasted from the late 1800s until after the First World War mainly across America. The reason for the second decline of the atrium is not entirely known, however it may have resulted from a combination of causes: just as in Europe, the buildings in the United States were also plagued by fires; the new plan types and styling of the International Style were beginning to take hold on architects; and the constricting postwar economy left little room for atria.

### The Third Era of the Modern Atrium

Almost two-thirds of a century passed before the atrium space returned to the interests and developments of the architectural community. As mentioned, its decline over those years was never fully understood, but its resurgence in the mid twentieth century was rooted in the many faculties the atrium offered. Of the most significant were: urban renewal, financial return, conservationism, and conservation of energy.

The atrium's aptitude for assisting in urban design strategies has been useful in many ways. With the modern day shift from single building projects to multiple building developments and urban districts, the atrium coherently relates these complexes, or volumes of buildings, together by acting as a mediating public element.<sup>26</sup> The spaces an atrium creates add to the public space in the city and are even able to tie into or extend existing public plazas. Furthermore, by providing protection from the outdoor climate, the atrium provides places for people year round. Simultaneously the same space adds



fig. 1.16 - Contemporary image of the Brown Palace atrium, the first identified 'atrium hotel'

meaningful pedestrian sequences in the city when pedestrian thoroughways and interior pedestrian systems connect into interior building atria. This often leads to the atrium space acting as an urban renewal catalyst. Additional amenities can be offered within the atrium, such as shops and services within an inviting environment of landscaping, fountains and exhibitions. The atrium also has no required shape or size, easily lending itself to complex or unusual site shapes. As a result an atrium is easily included and/or allows spaces which were not very useful, to easily find use as public spaces working towards urban strategies.<sup>27</sup>

The financial return the atrium space provides has shown itself to be a good investment when designing a new building. The profitability of an atrium building is in its ability to attract higher rental rates, more sales and/or higher occupancy rates. This has a lot to do with the attention the atrium space attracts and its ability to create a building's identity. The additional amenities the atrium space can provide: sunlight, greenery, indoor public space with shops and services, among others, is another aspect which attracts renters/buyers. A further attractive aspect of the atrium is its ability to provide additional window views. Windows in the interior atrium allow incoming light into the centre of the building as well as interesting views out, such as watching the activity on the atrium floor. Even the energy saving potential from the atrium's amenities is seen as an economical benefit. For example, less artificial lighting as a result of incoming sunlight, results in lower utility bills. Consequently the atrium's post-construction financial advantages outweigh the economic burdens of building the atrium in the first place. This offsetting effect has always been a major force in the atrium's proliferation and marketing advantage.<sup>28</sup>

The ability to help conserve old buildings and in turn conserve/reduce building materials has shown the atrium's usefulness as a conservational tool. By aiding in the adaptive reuse of existing buildings, such as covering, and thus converting, old courtyard buildings into innovative atrium buildings and hollowing out deep floor plates to include atria for useful shallower depths, has helped give second lives and revitalized roles to many old and forgotten buildings. By incorporating atria into such designs, the need for new construction is reduced while still tendering new and exciting possibilities. Likewise, extensions and renovations to existing buildings can be linked by atria, preserving the old façades and mediating between old and new. Thereby the atrium acts as a tool for addressing low impact construction with adaptive reuse projects. As well, atria themselves can be functionally dynamic. This offers a

place within a building that has many uses, adding diversity to the building program and allowing the atrium to adapt to the changes the building has over time with changing owners, users and uses. Thus the atrium itself becomes an ongoing tool for adaptive reuse, which can prolong the building life, conserving materials and energy for replacement and/or new projects.<sup>29</sup>

Working to assist a building's tempered indoor environment, the atrium can facilitate conserving and reducing energy. The potential to reduce energy has always made the atrium an attractive architectural feature. The interest in this aspect first peaked during the 1970s energy crisis and more recently again with the re-emerging energy crisis of the twenty-first century. Depending on the design, the atrium can *conserve* energy in several ways: acting as an environment (climate) buffer between indoors and out; acting as a heat sink to store heat energy which is unwanted, or stored until later needed; acting as a collection zone for expired air, by being used as a bulk return air plenum. These examples show how by acting as a utility to the overall building, the atrium's transitional space can help conserve the energy which the building utilizes to maintain itself. Likewise, if designed appropriately the atrium can *reduce* energy demands in one or more ways: bringing daylight into the building to assist with electrical lighting; accumulating solar radiation to gain passive solar energy either for winter gardens or preconditioning incoming air; generating air movement by providing interconnected vertical space, which facilitates air buoyancy (stack effect) to naturally cause air movement. The atrium allows the energy which is naturally present outside to come in and have an effect to reduce the need for infrastructural systems to provide for the building.<sup>30</sup>

These appealing facilities, coupled with the growing technology to do so in a grander and more efficient manner, brought the atrium strongly into the later half of the twentieth century.

That is not to say that the atrium was completely lost during the early part of the twentieth century. Frank Lloyd Wright was a living link between the second modern atrium period and the third. Starting with the aforementioned Larkin Building in 1904, he never lost interest in the flow of space from level to level. During the period of atrium dormancy, Wright produced many aspiring designs incorporating the atrium space. For example the Johnson Wax (fig 1.17) headquarters in Racine, Wisconsin was built in 1936 and has many top lit spaces reminiscent of the atrium form. Furthermore, two atria are created using two and/or three levels of surrounding galleries placed around both the



fig. 1.17 - Johnson Wax HQ, ground level workroom, galleries are visible along the perimeter



fig. 1.18 - Wright's Marin County Civic Center with offices and gallery surrounding a central atrium



fig. 1.19 - The top lit central atrium with circling ramp gallery of the Guggenheim Museum in New York

entrance lobby and main office space, formalizing the vertical connection of space. Similarly Wright's prototypical V.C. Morris Store in San Francisco and follow up Guggenheim Museum (fig. 1.19) in New York were both top lit buildings with focal central spaces. Completed in 1949 and 1959 respectively, these two buildings share their distinctive spiral-ramp circulation schemes within the central atrium strategy. This brings natural daylight into the building atop the ramped circulation – a variation on the office gallery theme.<sup>31</sup> Taking Wright's work fully into the third era of the atrium was the Marin County Civic Center in San Rafael, California. See fig. 1.18. Initiated in 1957 near the end of Frank Lloyd Wright's life and career, the project was completed in stages over the course of the next decade. The layout of the building returned to the gallery accessed offices off of the surrounding central vertical space. Once again the top lit space brings light into each floor surrounding the atrium providing for the offices of the county services.<sup>32</sup> Not only did the atrium survive through Wright in the years between the second and third periods of development, but Wright's work offered inspiration for that which developed in the 1960s.

Therefore during the 1960s a noticeable resurgence of atria inclusion in buildings occurred, defining the third and ongoing era of the atrium. Unlike the previous era, the resurgence in the 1960s was not limited to the United States, as this re-development of the atrium occurred in developed countries around the world. Canada saw the atrium emerge in the work of Australian architect John Andrews. The emerging brutalist architectural style which Andrew's practiced, kindly took to large interior elements, such as atria. His design for Scarborough College (fig. 1.20a - c), completed in 1966 (present day University of Toronto at Scarborough), used multi-level corridors within the spine building to form galleries terminating in an internal courtyard 'meeting place'. Andrews' indoor public square was one of many initial examples of the reintroduction of the atrium space in the 1960s.<sup>33</sup> Similarly in Montreal, the design and completion of Place Alexis Nihon by Harold Ship also made use of an indoor public atrium. Designed and constructed as part of the new developments for accommodating Expo '67, the excitement surrounding the World Expo fuelled the experimentation for reintroducing the atrium in this commercial development. The Place Alexis Nihon complex was incorporated into the new city metro and maintained five galleried levels of offices and shops overlooking a covered square; see fig. 1.21 for an image of the atrium.<sup>34</sup>

In England, the atrium first significantly reappeared in two projects, the Liverpool Civic Center (which was never





fig. 1.20a



fig. 1.20b



fig. 1.20c

fig. 1.20a - Contemporary photo of the 'meeting place' atrium at Scarborough College

fig. 1.20b + 1.20c - Andrew's corridors at Scarborough College



fig. 1.21 - Current day photo of La Place Alexis Nihon in Montreal



fig. 1.22 - Model of the Liverpool Civic Centre proposal by Colin St. John Wilson



fig. 1.23 - The reading room atrium at the Cambridge History Library in England



fig. 1.24 - The atrium at the Ford Foundation Headquarters building in New York



fig. 1.25 - View of one of the twin atria found at the Antoinettes Graves houses, which was the predecessor to Portman's flurry of hotel atria which followed

completed beyond the design stage), and the History Library at Cambridge University. Although never completed, the Liverpool Civic Center (fig. 1.22) is seen as a significant milestone and precursor to what was to come in the following years. Designed in 1965 by famed British architect Colin St John Wilson, (best known for the British Library project in London, which took 35 years to complete between 1962 to 1997), the dramatic use of an enclosed interior atrium was brought to attention by the Liverpool Civic Centre proposal. The design consisted of four seven storey office wings, converging in a pin-wheel pattern to leave a central court. The court was covered by a glass roof and the galleries around it served as public counters for city departments – in essence it was an example of the typical modern atrium to come.<sup>35</sup>

The History Library (fig. 1.23) at Cambridge University was designed by James Sterling as part of the Library design competition in 1963 and after being selected, was completed in 1968. Here two multi-storey wings form an L-shape with the created corner space roofed over by a sloping glass tent. The intended glass tent is known as the reading room atrium. Corridors of the 'L' building overlook the reading room as well as having protruding balconies. The History Library stands as one of the first atria completed in England during the resurgence of the mid twentieth century.<sup>36</sup>

As mentioned, the works of Frank Lloyd Wright never truly let up during the gap years between eras. His work helped instil the atrium in the minds of American architects so that it could flourish in the 1960s. As a result it was in America that the resurgence of the office building atrium came to capture the attention of the entire world of architecture. The Ford Foundation Headquarters in New York City by Roche and Dinkeloo was both daring and brilliant in conception and execution. Finished in 1967, this variation on the previous era's office atrium, arranges a large scale atrium within an L-shape of 12 storey inward looking offices. This variant places the atrium on the street rather than surrounded by building. Similar in concept to the English's History Library, the Ford Foundation Building makes a much bigger statement. Beyond its amenity for the patrons of the building, the atrium is equally an urban gesture. Serving as a new kind of public urban space, the atrium (fig. 1.24) is designed as an indoor park to be used year round by city residents, the general public and the occupants of the office building. The atrium space is placed as a transition space between the city outside (42<sup>nd</sup> street, the adjacent city play park and neighbouring Tudor City residence) and the private inside (the surrounding offices). Working for the office as a communal



focal space while at the same time working for the city as a relief from the street – in both cases the atrium is a place of repose. Such a large and evocative office building atrium caused many designers to reconsider the possibilities of the atrium and rekindled the atrium office plan, as evident in the many which have been and continue to be built.<sup>37</sup>

Throughout all of these examples, one designer in particular played a major role in re-introducing the modern atrium space. John Portman, principal of Edwards and Portman Architects (shortly afterward John Portman & Associates with Edwards' retirement) based out of Atlanta, Georgia, produced projects that had a flair for a popular aesthetic, that along with consistent commercial success ensured the commissioning of many more. Portman first used the atrium as part of a Retirement Community called the Antoine Graves houses in 1963. Forced with a restricted site that could not accommodate typical three storey walk ups along with an open minded client who encouraged doing something interesting, Portman's response was 210 units which surrounded twin atria. Looking to create a social and open-air environment, Portman used simple apartments which opened onto galleries as part of the atria. See fig. 1.25. Both atria are covered to diffuse sun and block rain, yet are still open to the outside to allow air to pass. Allowing the atria to rationally include circulation, the atria themselves are subdivided by a bank of elevators and stairs at their centre. The building was a big success with the tenants, much admired and considered too good of a scheme to simply be a residence, perhaps best suited for a luxury hotel.<sup>38</sup>

In 1967, Edwards and Portman did exactly that, place a grand scale atrium into the design for the Hyatt Regency Hotel in downtown Atlanta. The Hyatt Regency Hotel had as provocative an influence upon the future of hotel design as the Ford Foundation Building in New York had upon office building design. The atrium here was something the world had never seen before and took observers by surprise, revealing a bold scheme for a hotel or almost any building. At the centre of the building, the hotel's atrium (fig. 1.26) measures 36 meters along each side square and rises the full twenty three storeys. Covered by an intriguing skylight and surrounded by a clearstory, this grand atrium maintains balconied galleries on each floor which serve as single loaded corridors for the guest rooms. To complete the atrium, the elevators have been placed within the atrium to fully animate the vertical motion which is the essence of this space. The Hyatt Corporation officially used the term 'atrium' for their hotel forever instilling it in contemporary design vocabulary. As for the atrium building phenomenon, the Hyatt Regency Hotel



fig. 1.26 - The atrium at the Hyatt Regency Hotel in Atlanta, Georgia

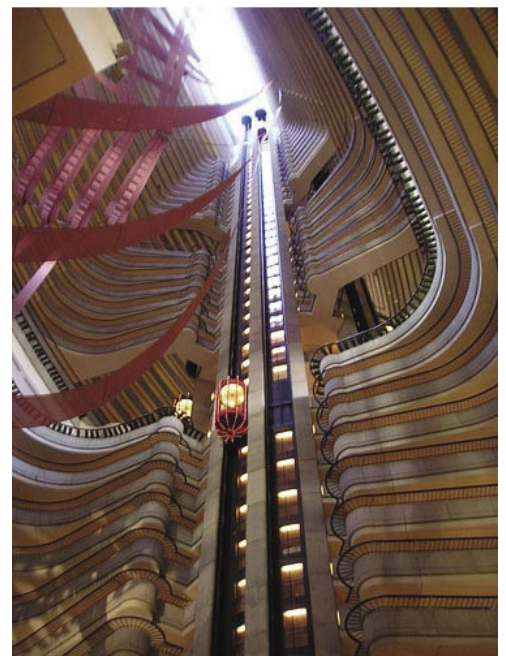


fig. 1.27 - The atrium at the Marriott Marquis Hotel in Atlanta, Georgia; built by Portman after his success with the Hyatt

perhaps did the most for creating a sensation, as occupancy rates for the hotel made owners and their competitors sit up, permitting the atrium movement to boom.<sup>39</sup>

In the period since the mid 1960s the atrium concept has enjoyed a great revival among architects, clients and the general public. Ranging in uses from the practical to the aesthetic and in appearance from the unrefined to the absolutely elegant, the modern atrium has found a place in many architectural designs and typologies to continue to be a staple in our current design era.

## 1.4

### Identifying the Atrium Today



fig. 1.28 - The Tokyo International Forum's grand atrium

As evident in the historical synopsis, over the course of time the modern atrium's substantial development was intertwined with developments in materials, engineering, and society along with changes resulting from cultural growth and aesthetic tastes. Today's atria could be considered part of the third era of the modern atrium, yet the modern atrium's unprecedented frequency in buildings since the third era's beginning would more likely suggest that it has outlived that 'era' and is here to stay. All the same, in the forty years that has passed since its re-emergence in the mid 1960s, much has developed and evolved.

The 1980s saw the atrium take root around the globe, as for the first time the atrium was seen as a permanent fixture in the architect's repertoire. Europe and Japan re-invested interest in the atrium concept. The preference for low-rise urbanism in Europe encouraged a return to the courtyard form on which the atrium is based, giving rise to many new opportunities in downtown developments. The demand for higher densities in the Far East, coupled with a thrill for the spectacular, produced some fantastic atrium examples.<sup>40</sup> The Tokyo International Forum was designed by Rafael Viñoly Architects for the 1989 design competition. An astonishing sight, it was a fruit born of this 1980s trend, though not completed until 1997. See fig. 1.28.

The firm grasp the atrium had secured on architectural design was also attributed to the continued technical advances and standardized fire regulations and codes. During the third era of modern atrium development, the design of large inter-floor spaces was specifically addressed in building code. Regulations included measures for controlling smoke during fires which so easily spread within the open area of an atrium (see Appendix C for the current codes for buildings in Ontario). By requiring such things as smoke baffles and mandatory sprinkler systems,





fig. 1.29



fig. 1.31

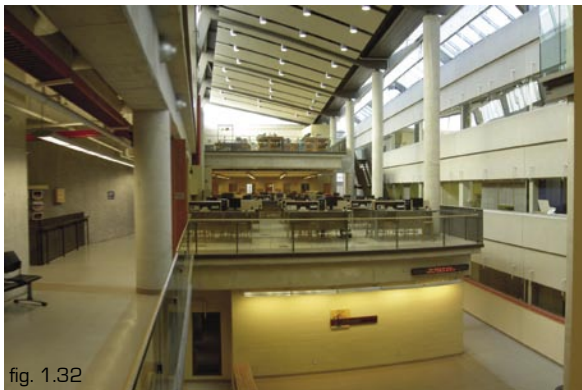


fig. 1.32

fig 1.29 - Credit Valley Hospital Cancer Care Centre

fig. 1.30 - Thunder Bay Regional Health Sciences Centre Atrium

fig. 1.31 - Technology Wing at Sir Fleming College

fig. 1.32 - Beamish Munro Hall

fig. 1.33 - High Park Lofts

fig. 1.34 - Toronto Reference Library



fig. 1.30



fig. 1.33



fig. 1.34



fig. 1.35 - A shopping centre atrium, as seen at the Toronto Eaton's Centre



fig. 1.36 - The atrium at the mixed use Queen's Quay Terminal

emergency fire management was better addressed and secured a sense of fire safety, the absence of which had been a setback in the early years of atrium development in Europe and America.

These and other factors have led to an evolution occurring in the application of the concept. Most significant is the lateral propagation in thinking about the possibilities of atria in architecture, as the atrium concept has been adapted to new roles and extended to new types of development. In recent years it has become common place to see atria as part of hospitals (Thunder Bay Regional Health Sciences Centre and The Credit Valley Hospital in Mississauga), schools, colleges and universities (The School of Architecture at the University of Waterloo, The Technology Wing at Fleming College and Beamish Munro Hall at Queen's University are a few of many seen in this thesis) as well as libraries (The Toronto Reference Library and The North York Central Library) and specialized housing (High Park Lofts, The Atrium on Queens Quay and the Strachan House, all in Toronto). Thus the atrium concept has evolved to find a place in many accomplished areas of architectural design beyond offices, hotels and buildings of civic significance.

Likewise, the variation of atrium scale and complexity has come to include both small and large, ranging from very simple to multifaceted designs. Atria of unprecedented scale have been completed all around the world, creating higher and larger atrium volumes. Some regional examples can be seen in large multi-use centres such as the Toronto Eaton's Centre and Queen's Quay Terminal, also in Toronto. See fig. 1.35 + 1.36. The large scale of these atria represents significant technical accomplishments which simultaneously act as powerful design elements within the architecture. Greater intentions for the atrium add to its complexity: taller, wider, managing daylighting, managing temperature, vertical circulation, and horizontal circulation are just some of the many possibilities. Designs which use atria as major energy conservation design strategies, add further technical complexities to the atrium and its role. The Mountain Equipment Co-op Building (fig.1.37) in Montreal and the York University Computer Science Building (fig. 1.38) in Toronto are examples of energy conserving designs, where the many facets of the atrium space not only act socially and aesthetically but also work practically for the energy conservation of the indoor building environment.

Conversely, the atrium concept has been applied to small and simple spaces. These smaller atria find a place as part of lobbies, building hubs or light wells which demonstrate vertical tendencies. Their size is often related to the overall building scale, which is also more modest. These understated examples



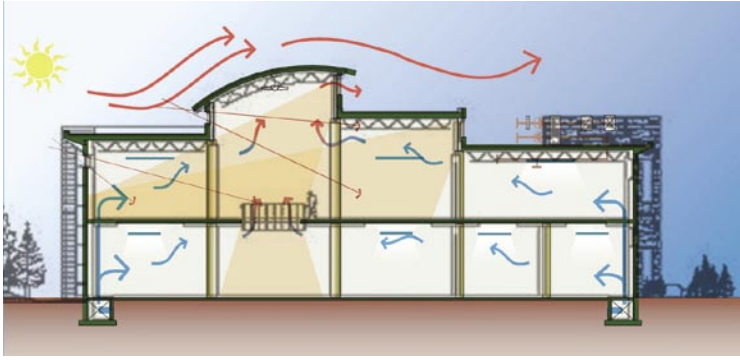


fig 1.37 - Section diagram of the Mountain Equipment Coop building in Montreal showing the passive daylighting and air movement accomplished with the central atrium space

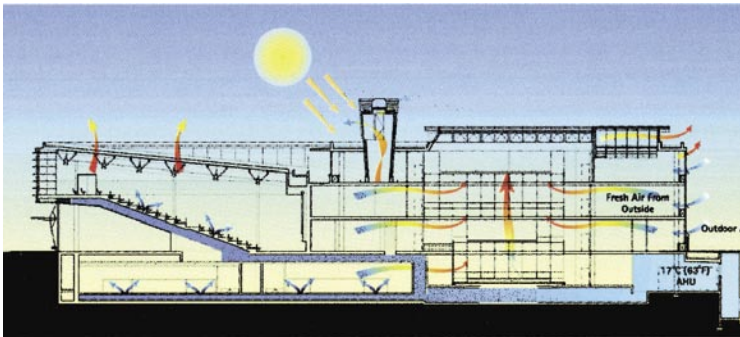


fig 1.38 - Sectional diagram of the York University Computer Science building showing the passive air strategy accomplished within the building

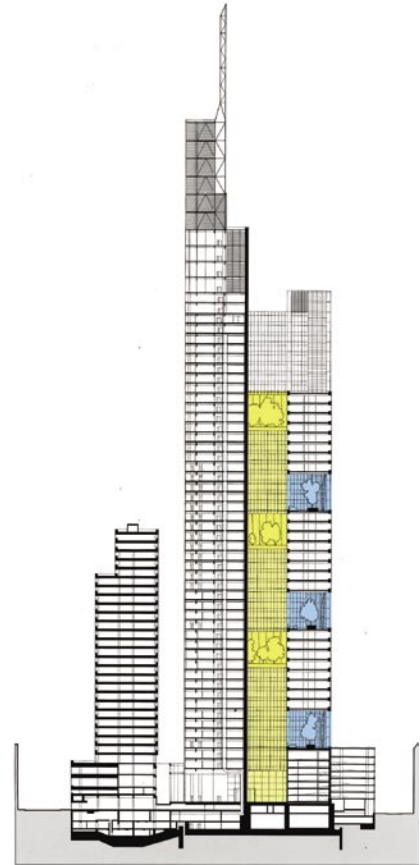


fig 1.39 - Section of the Commerzbank Building showing the multiple vertical atria



fig 1.40 - Section of the Centre for Cellular and Biomolecular Research at University of Toronto, showing the multiple vertical atria and denoting the passive air movement through the building

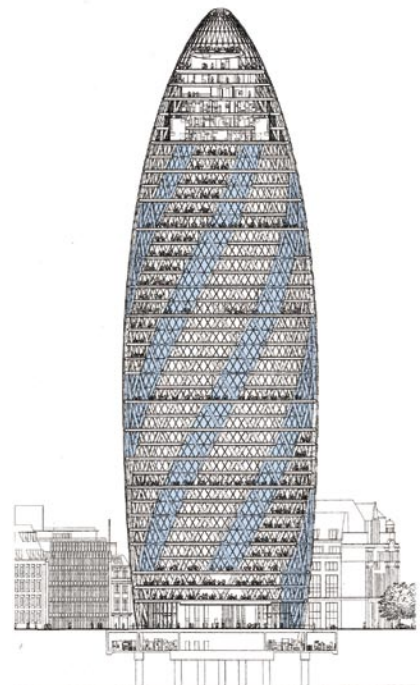


fig 1.41 - Swiss Re Building in London, England showing the multiple vertical atria which spiral up the sides of the building

#### Simple Atrium Forms

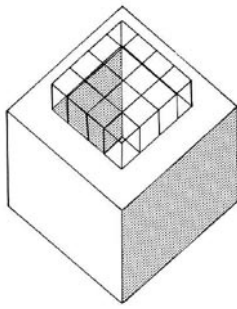
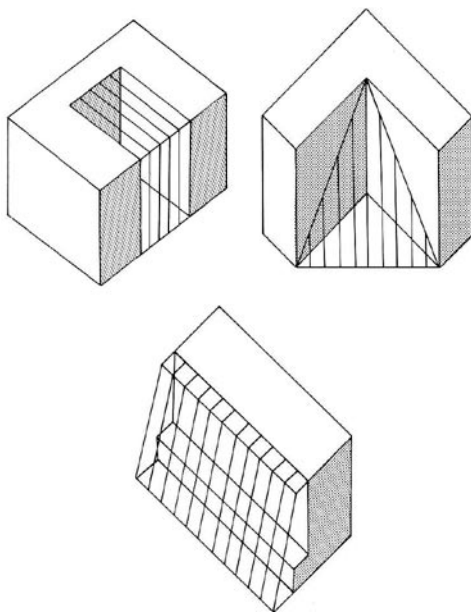


fig. 1.42 - Closed Atrium



Clockwise from top: fig 1.43 - One Sided Atrium, fig 1.44 - Two Sided Atrium, fig 1.45 - Three Sided Atrium

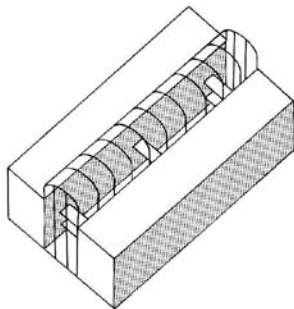


fig. 1.46 - Linear Atrium

of atria are similar in concept yet lack in lustre; nevertheless their downsized representation of their larger counterpart's concept is just another example of the atrium's evolution and propagation.

Lastly the location and form of the atrium within a building is also an ever changing facet in architectural design. The atrium can be located centrally on the interior, fully surrounded by building; or on the perimeter of the building, comprised of at least one exterior wall. Atria take different forms depending on the conditions of the building they show up in, as building layout and site conditions change from situation to situation. This creates plans ranging from square to oblique, from geometrical to organic and from long and slender to short and stubby. The frequency of atria in one building and multiple stacked atria in a single building is another recent development. Large scale examples can be seen in the Commerzbank Building in Frankfurt, Germany and the Swiss Re Building in London, England as well as more locally in the Centre for Cellular and Biomolecular Research Building at the University of Toronto, see fig 1.39 to 1.41. Here the atrium element is spread throughout the building and/or is broken up into different vertical sections which are stacked throughout the building vertically. All these variables of the atrium space have evolved so that the intended form, placement and use of each atrium vary from building to building.

#### Atrium Generic Forms

From the atrium's development and propagation, generic atrium forms have been identified. Initially compiled by Richard Saxon in his *Atrium Buildings: Development and Design*,<sup>41</sup> and further adapted by Michael Bednar, in *The New Atrium*,<sup>42</sup> a comprehensive cataloguing of atrium forms can be illustrated using a combination of the two authors. Three types; simple, complex and partial, consisting of five simple forms, four complex forms, and the partial atrium are noted below, and examples shown.

#### Simple Forms

*Closed Atrium* – The classic or standard form defined by being surrounded on all four sides of occupied space; it can be in any shape in plan; source of exterior connection is through skylights or roof clerestory. See fig 1.41



*1, 2, or 3 Open Sided Atrium* – An atrium with one, two or three sides on the perimeter of the building, either partially or completely glazed; the roof may or may not be glazed. See fig. 1.42 to 1.44

*Linear* – An atrium with occupied space on opposite sides of the atrium and circulation connections across; usually an elongated rectangle in plan; all or partially skylit or clerestory glazing with the atrium ends may be glazed or defined by building elements. See fig. 1.45

### Complex Forms

*Bridging Atrium* – An atrium placed between two or more buildings to connect multiple buildings together, creating interior urban space and unifying the block, complex or district. See fig. 1.46

*Podium Atrium* – An atrium located at the base of a building or tower which spatially organizes only a part of the building. See fig. 1.47

*Multiple Lateral Atria* – More than one atrium within a building, each laterally disposed and spatially organizing a section of the building. Each one is usually an atrium type of its own. See fig. 1.48

*Multiple Vertical Atria* – More than one atrium within a building, each vertically stacked and spatially organizing a section of the building, each one relating a set number of floors together. See fig. 1.49

### Partial Forms

*Partial Atrium* – Any atrium which resembles one or more of the simple forms yet does not organize or relate the whole of the building; only relates a set number of floors; usually a smaller scale atrium due to its limited relationship to the rest of the building.

Many other hybrid arrangements are possible by elaborating from one or more of these generic forms. As a result this classification of atria is not absolute, and is based on a judgment born of a comparison of characteristics.

Complex Atrium Forms

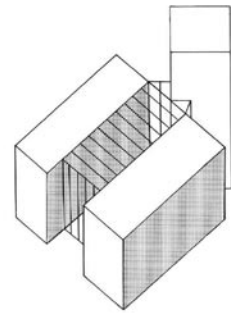


fig. 1.47 - Bridging Atrium

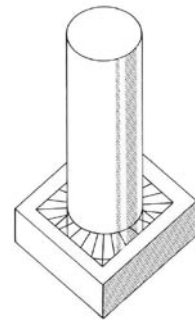


fig. 148 - Podium Atrium

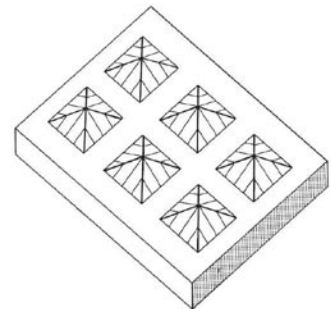


fig. 1.49 - Multiple Vertical Atria

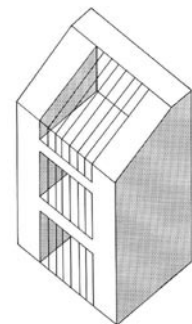


fig. 1.50 - Multiple Lateral Atria

The atrium of today has not deviated far from its 1960s renaissance; it has only expanded in definition. The atrium today can be seen as the modern building's inner piazza (public space), a sometimes soaring, multi-storey interior space which maintains some connection to the outside. The atrium is typically used as a key architectural feature in main entries, public circulation areas or as a special destination within a building – often a high traffic area. A typical quality of atrium design involves skylights and generous glazing areas that provide an infusion of natural light, making them a prominent building area well suited to serve ceremonial and social functions. Atrium amenities often include seating, meeting or waiting space and offer main conduits to significant rooms or hallways to the rest of the building. In addition, some atria are filled with plants, trees and water features which thrive on the incoming sunlight, creating tranquil meditative spaces – so much so that the health benefits of atria in buildings such as hospitals have become a topic of study.

As in its earliest days, the atrium has continued to turn heads and keep favour with its many marketable faculties; as previously mentioned, the most significant of these are: the atrium's ability to assist in urban strategies, its strong economic ability to provide return on investment, its ability to help conserve or recycle existing buildings, and its potential to reduce building energy consumption. As this thesis focuses in on the latter two, conservational attributes of the atrium, it can also be said that over the course of the atrium's inception and proliferation the current version of the modern atrium still offers attributes which further this thesis' cause. To be able to continue to assess the trends of such conservational attributes within the atrium, in light of sustainability and 'green' building design, the specifics of how the atrium accomplishes this will follow.

As the thesis focuses in on the attraction to, and the trends surrounding the atrium's conservationism, it is appropriate that a discussion be started which validates the investigation of conservation. A brief outline of the current realities of energy consumption and its relation to buildings in Canada can be used as a departure point for placing our need for conservation into perspective.

Canada's continuously growing appetite for energy is well documented. As with most developed countries where energy abounds, increased individual consumption levels are permitted. Canada ranks an embarrassing 27th out of 29 nations in the OECD (Organization for Economic Cooperation and Development) in terms of efficient energy use per capita. Canadians consume 6.19 tonnes of oil equivalent per capita per annum. This is almost double the OECD average of 3.18 tonnes of oil equivalent per capita, and more than five times the world average. Only residents of other energy rich countries, such as Iceland and Luxembourg use more energy per capita than Canadians. In 1997, Canada's total consumption amounted to 187.5 million tonnes of oil equivalent. These amounts place Canada 4th out of 29 OECD nations for total energy use, with only the United States, Germany and Japan using more energy.<sup>43</sup>

Annual reports in Canada have also shown energy demands increasing annually. In 2003 consumption rose 3.0% from the previous year, fuelled by gains among the nation's industries and growing residential and commercial activity.<sup>44</sup> A further breakdown in 2004 shows Commercial and Institutional establishments consumed nearly 945 million gigajoules (GJ). This is an amount equivalent to the average annual consumption of approximately 7.9 million Canadian households, and nearly five times the amount of energy used by all private dwellings in a city like Toronto.<sup>45</sup> Adding the Commercial and Institutional energy consumption to the Residential building energy consumption (1381 million GJ), and Canadians are consuming a total of 2326 million GJ of energy to heat, cool, light and service their building needs. This represents approximately 35 percent of Canada's total annual energy consumption (and can represent up to 50 percent in most developed countries). Canada's building energy intake is overshadowed by our abnormal energy consumption in the Transport and Industry sectors (related to Canada's geographical size and abundance of industrial raw material extraction).<sup>46</sup>



fig. 1.51 - The sprawling built landscape of Los Angeles, presents a spellbinding image of construction and growth

A similar study of building energy usage in the United States shows that on an annual basis, buildings in the US consume 42% of America's overall energy (35% in Canada) and of that, 68% of its electricity (54% in Canada). As a result, buildings in the US generate 35% of the carbon dioxide (the primary greenhouse gas associated with climate change), 49% of the sulphur dioxide (which reacts with water and atmospheric oxygen to form sulphuric acid to create acid rain), and 25% of the nitrogen oxides found in the air.<sup>47</sup> With the escalating impact of greenhouse gases on world climate, along with the world's dwindling supply of fossil fuel, and increasing concerns for the security of energy supplies it is essential to discover ways to reduce and conserve energy, ensure efficiency, and utilize renewable fuel resources within our facilities.

These facts, together with the long life of buildings, means that action on energy conservation and planning our future energy supply are interconnected with the crucial role buildings play in our growth and resource consumption. Furthermore, as our population grows (more than tripling in the last century to 6.5 billion<sup>48</sup>) and the affinity for western lifestyles spreads (as more countries strive to become developed), our energy demanding built environment also increases. Emphasising again, that as a world culture we must all reconsider our habits and patterns of energy and resource use or face that we may actively outlive the planet's potential. In a newly arrived age of blackouts and brownouts we are coming to understand the need to modify our demands by employing the concept of *sustainability*.

#### Conservationism within Sustainable Architecture

The dynamics of architecture are no different from other human activities or interventions which impact the environment. Within a given ecological setting, human cultures evolve an adaptive response to their environment (such as a siesta which deals with the midday heat). Cultures develop technologies as a means of fulfilling individual and collective needs and desires (air conditioning to deal with the midday heat). These technologies, in turn may result in environmental impacts or stresses on the ecology. Ecology, culture and technology evolve and adapt, but the relationship is not always symbiotic, and is in some cases dysfunctional. In response to this understanding, our values are changing and re-working towards ideas of 'green' and sustainable architecture. Viewed from this perspective, sustainable architecture requires an architectural culture

which understands and contributes to the harmonization of environment and technology.

Sustainability itself is defined differently within and between cultures, and its definition has changed over time. But we can adopt a broad consensus definition if we use the one defined by G.H. Brundtland in the World Commission on Environment and Development:

“Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activity.”<sup>49</sup>

This definition implies that sustainable development or evolution envelops a large range of human activities, architecture being among them. Sustainability is not a specifically architectural problem, but rather a global, cultural problem in which architecture is discovering its emerging role.

The idea of buildings being sustainable and tapping into natural forces to provide healthy and comfortable environments is ages old. Unfortunately, over the course of the twentieth century contemporary design has veered away from these practices in light of readily available external energies which provide amenities for the building. With the many concerns previously noted, we are seeking out architectural design which addresses the many aspects of sustainability and are beginning to produce buildings that are not only efficient, but feature low environmental impact with intelligent design. Although not a given, sustainable architecture can influence and shape the culture which it is in. The relationship between culture and these buildings is an important contributor to the designer's goals and intentions. The *desire to be* sustainable (culture) is what will *allow* a building to become sustainable. As more practitioners report on the public response to the impact of sustainable issues, it is clear that sustainability is becoming a supporting factor of design. Substantiating evidence can be observed in an interview with Brett Gregory President & CEO of *Mithun*, a design firm based in Seattle:

"Economics, health and values are driving the worldwide movement toward environmentally intelligent design. In the European Union, carbon limits and resource costs are creating a huge demand for smart buildings. Community values have brought forth new neighborhoods, and whole cities, such as Malmö, Sweden, have adopted very aggressive goals for environmental performance. Here in North America, we will see that demand accelerate even faster as resources become more expensive, the links between health and indoor air quality become better understood, and knowledge of every individual's environmental footprint comes to the forefront. In the private sector, marketplace demand will give environmentally intelligent buildings more economic value. People are recognizing this. The education of architects, designers and engineers in sustainable design has accelerated exponentially because our clients are demanding it."<sup>50</sup>

Amidst our changing views, we are returning to practices where buildings take better advantage of the sun and wind to help provide for the building interior, which is one of many attempts at creating sustainable architecture. There are many other approaches to adding sustainability to the architecture these days, whether it is reusing materials, reducing embedded energies in construction, high efficiency design strategies, or integrated renewable energies. Not surprising these approaches tend to be rooted in the concept of conservation: reusing materials is the conservation of materials, reducing embedded energies is the conservation of energy during fabrication, efficient design is the conservation of energy needed to maintain the building, and integrated renewable energy (using geothermal, solar and wind energy) is the conservation of already existing natural energy. Thereby, conservationism is central to the idea of sustainable architecture.

As sustainable architecture gains momentum, the realization of conservational design becomes more prominent throughout our cities. Architectural elements such as the modern atrium, which contribute to sustainability by their ability to conserve, can be called upon to fulfill their potential and participate in this movement. Thereby the atrium most certainly has value within the sustainability discussion, value growing from what it can offer. It is the intention of this thesis to focus in and further elaborate on the atrium's conservational characteristics. By doing so, an understanding of these characteristics can be used to evaluate completed built examples used in the survey.





fig. 1.53 - The University of Waterloo's School of Architecture building



fig. 1.54 - The centrally located atrium at the School of Architecture

and urban fabric while offering a new and exciting interior to address their new use. Simply by reusing old buildings the need for more construction is reduced, allowing materials to be saved (and in turn embedded energy) and garbage to diminish.

Along the same lines of renovation and conversion, the atrium has become a popular tool for reusing historically significant buildings and integrating new with old. With new and expanding extensions or renovations, the need to maintain the integrity of existing buildings can cause problems for the addition of modern design and construction. The incorporation of an atrium space as a mediator, between the new and old, alleviates the tension between the architecture and allows the old to co-exist with the new. Furthermore old and sensitive facades or building components can be restored and protected with the help of an atrium to continue to be used rather than be demolished and lost in the renovation. Thereby by acting as a mediator, the atrium merges projects together, and is a catalyst for the reuse of old buildings in new projects.

The versatile space many atria offer is another contributing factor towards the atrium's reusability. Atria which include a portion of open or social space can accommodate many differing functions adding diversity to the building program (often for social settings). Thereby the atrium is a useful place not only in its day-to-day functions, but also offers space which can accommodate occasional or unusual functions for the tenants of the building. When used as a multi-functional space (alleviating the need for special rooms or spaces), the atrium (depending on the layout and design) has been known to be used for semi-formal or formal gatherings, act as a temporary gallery or display space and even provide as an event hall for lectures or theatrical and musical performances. The diversified character of the atrium allows it to continue to provide these multi-functional amenities which are still useful when the building changes owners, users and uses. Thus the atrium itself becomes an ongoing tool for adaptive reuse, which can prolong the building life through the course of many tenants, conserving materials and energy for replacement and/or new projects.

The methods of adaptive reuse and future reuse potential can be seen in the School of Architecture Building at the University of Waterloo. The School of Architecture building (fig. 1.53) is a recently completed adaptive reuse of a hundred year old silk mill. As part of the renovation of the old building an atrium was carved out within its existing floor plates to be used principally for occupant circulation and building organization. Overall the



building conserves much of its original industrial character, with original floors, exposed painted brick and wooden structure—however it is also a new technologically progressive institution—the central atrium mediates this junction by incorporating contemporary structural and finishing choices and seamlessly bridging the gap between old and new. It allows the occupants to enjoy the positive aspects of the original building while, along with structural changes, further opening up the space for light entry and circulation. The atrium is also an attractive addition as it creates an impressive aesthetic and emotional response. See fig. 1.54 for an image of the atrium space. The design for the school of architecture has fully exploited the potential of the old silk mill. The success of the renovation is easily observed with its historical brickwork and converted spaces, along with the new found life at its hub, with the new airy atrium.

The future reuse potential of the school's atrium can be seen as it is a diverse space continuously being used for many different functions. From student installations and displays of work to musical performances, formal receptions (fig. 1.55) and everyday gatherings, the atrium is a vital element within the building. On a daily basis, a continuous flow of students and staff move throughout the building using the atrium area for both vertical and horizontal movement. The centralized location allows the atrium to service the majority of programmatic spaces as all major spaces are connected through the circulation of the building with the atrium at its core. As a result of the many activities possible in the atrium, the space has value for future reuse potential; if the building was used for another purpose the atrium would still be very useful in its many current capacities.

See Appendix A.1 for further elaboration on the University of Waterloo School of Architecture.

### *Incorporating Daylighting Strategies*

The cherished value of daylighting is universal throughout all architectural designs. Likewise, daylighting has come to be expected as part of an atrium, and is nearly always implemented or at least attempted. If there is no visual connection to the outside the architectural space would not be called an atrium. Sustainably, the use of daylighting, a free energy source, can be useful in an atrium in one of two ways: daylighting can provide natural light which offsets the use of electricity, the most expensive and refined energy source; or similarly, daylighting can provide solar gain (radiant heat from the sun), which can offset heating, usually accomplished with non-renewable gas or oil. Both utilizations of daylight are



fig. 1.55 - University assembly which used the school's atrium space as an event hall

beneficial in maintaining the interior building environment while requiring less external energy for running and maintaining building amenities. Additionally, using natural light within the building rather than artificial light greatly benefits its occupant's well being and encourages plant growth (commonly found in atria) by providing the full spectrum of light.

The infiltration of natural daylight is readily accommodated by the atrium with its substantial glazing which lets the light in and its volume penetrating into the building to distribute the light to the its core. It is the atrium's ability to bring light into the inner portions of a building which make the atrium's impact on and presence in the building greater than typical fenestration. Usually some form of overhead source, either skylight or clearstory is optimal for bringing daylight into the building, but glazed side walls are also often used to bring light into the building along with providing views and/or connections to exterior spaces. Although it is worth noting that side glazed walls are not optimal, as glazed walls have to deal with other vertical obstacles (such as trees or other buildings) and directional limitations from incoming light over the course of the day. A case can be made for admitting both southern and northern daylight components: the southern for its intensity and brightness and the northern for its constancy and even colour. The use of southern light also requires that measures be taken to control the unwanted aspects, such as glare and solar gain. Eastern and western light are fairly harmless in the winter months, but can become more troublesome in the summer. Eastern light can often be too direct in the summer mornings and western light in summer afternoons can be as hot as from the south. As a result the need for proper control may also be required for east west facing glazing. Daylighting can be made useful in all climates, and especially useful in commercial and institutional buildings where high light levels are required during the daytime and the building usually remains empty during the night. An atrium used in these buildings can increase the amount of natural light reaching into the building and thereby reduce the need for artificial lighting and in turn reduce electricity loads. Furthermore, a byproduct of natural lighting is the reduction in cooling energy needed for heat generated by electrical lighting.

The incoming solar gain can also be exploited within the atrium. Depending on how the atrium is designed, the heat gain can be used to heat the atrium space to either warm the air in the atrium, or store the heat for later use. The heating of the air within the atrium is similar in concept to a greenhouse, where the solar radiation becomes trapped inside the atrium

and heats the elements inside. This heating warms the air within the atrium and is useful in winter when buildings require heat for the occupants comfort. The solar gain can help maintain a warm buffer between outdoors and indoors, using the atrium as a buffer or transition space. Or alternatively, the heat can be used to passively precondition incoming fresh air which is run through the atrium from the outdoors before being actively conditioned and sent throughout the rest of the building. As for the storage of heat within the atrium, the materials which the atrium is made of play an important role for the solar gain to be put to use in the thermal mass of the atrium. A large amount of concrete is very useful for storing the heat as the concrete acts as a heat sink to store heat energy which is unwanted or stored until later needed. The heat is later released when the air temperature cools down and heat is needed to maintain a comfortable level. By capturing the solar gain the atrium can help reduce the need for energy (gas, oil and electric) to heat and condition the indoor environment during the cold seasons.

To maintain some control over the incoming daylight, either to increase or decrease the quantity of light, a number of details can be designed into the atrium. To increase the amount of time during the day light enters the building, the use of heliostats or similarly a series of mirrors, can redirect falling light more directly to usable work areas. The use of any design which helps redirect light can further increase the amount of usable daylight and decrease the amount of electricity to power artificial lighting.

When too much light enters the building, it tends to create glare and is too direct for working areas, resulting in the need to decrease the intensity or diffuse the light. In this case, the daylight can be controlled by a number of ways: using tinted or fritted glass, using louvers or shading devices, or incorporating overhangs for use on vertical glazing. These daylight deterrents are most important for controlling solar gain, which is not desired year round. A roof overhang or horizontal sunshades are necessary to keep the high southern sun from penetrating. With the use of tinted or fritted glass (fig. 1.56) the amount of incoming light is permanently controlled year round. Whereas the use of louvers, overhangs (fig 1.57) or shading devices is more likely to be variable or work seasonally with the changing angle of the sun. In any case, for the atrium to be completely successful using the energies of the sun the atrium must both use and control the incoming daylight to make sure that not too much solar gain is accumulated which will work against the energy savings, such as requiring additional energy for cooling.



fig. 1.56 - Close up of fritted glass pattern used on the south facing facade



fig. 1.57 - Atrium clerestory glazing with exhaust vent and roof overhang behind



fig. 1.58 - The HP Science and Technology Centre at Centennial College



fig. 1.59 - Looking down into the east atrium from the third floor at the HP Science and Technology Centre

Many of the daylighting methods can be illustrated using the HP Science and Technology Centre (HP Centre) at Centennial College. The HP Centre (fig. 1.58) is a new high energy efficiency building which has incorporated 5 rising atria as part of its design. All atria rise above the fourth floor ceiling providing a clearstory space that allows natural light to filter through the atria into the center of each wing of the building. See fig. 1.59 for an example of one of the full height atria. Centrally located in each wing, light-filled interior hallways run along either sides of an inner atria zone making use of the generous amounts of natural light. The openness and transparency allow the light, colour and weather of changing seasons to be drawn into the interiors and reduce the need for artificial lighting for most of the daytime. The infusion of natural daylight is a large part of the building's design strategy to provide high energy efficiency which substantially reduces operating and maintenance costs.

To control the daylighting the HP Centre has employed a few techniques to diffuse the daylight and reduce the solar gain. Across the front of the building, which mainly faces south, the control of light and solar gain is most important. Fritted glass (fig. 1.56) has been used on the vertical glazing to help diffuse the direct light. In addition, the incorporation of large overhangs as part of the façade design helps control solar gain from the high summer sun. Similar overhangs (fig. 1.57) have also been designed over the clerestory glazing at each of the full height atria. These overhangs reduce the amount of direct light coming into the building, creating soft diffused light for the inner building hallways and rooms.

As a further means of energy efficiency the HP Centre employs a large amount of exposed concrete on the interior to provide a high thermal mass to exceed the ASHRAE 90.1 standard for energy efficiency by 40%.<sup>51</sup> Thereby in the summer, what heat is in the building can be absorbed into the thermal mass to be released at night, rather than warm up the building spaces. Conversely, in the winter, the solar gain which comes from the lower winter sun enters through the south façade (no longer blocked by the overhang) and stores its heat in the exposed concrete floors and walls to help reduce the amount of heating required for the building.

See Appendix A.2 for further elaboration on Centennial College's HP Science and Technology Centre.



### *Incorporating Passive Strategies for Air Movement*

Good air circulation is crucially important to the comfort and well being of occupants in the indoor environment. A conservational approach to air movement within buildings involves making use of atrium spaces to passively move air through the building. The movement of air without the need for mechanical force and the use of energy is considered passive. The passive strategies for air movement can be useful in one of two ways: passive air movements can help provide ventilation which maintains the indoor air quality and offsets the use of electricity, used by air handling units (AHU), to pump the air through the building; similarly, passive air movements can assist in cooling the building, offsetting cooling loads and electricity demands needed to run the air refrigeration units. Both utilizations of air movement are beneficial in maintaining the interior building environment to require less external energy for its running and maintenance.

Passive motion by thermally driven convection is based upon the stack effect in atria (see Appendix Section D.3). The large heights within atria naturally stratify air of different temperatures, and therefore densities, creating a vertical pressure differential. The hot air rises to the top of the atrium wanting to escape and draws air from surrounding spaces to fill the void and thereby setting up convective flows. By providing a place for air stratification the atrium space creates pressure forces, which are used to move air and reduce the need for electricity used in electric fans. With the inclusion of vents and intakes the passive movement is then useful to keep air moving through the building and provide the air exchanges needed for maintaining the indoor air quality (IAQ).

The exchange of air through a building using the stratification of air in the atrium will also cool the building. As the hot air pushes to escape through the top of the atrium, it is released through vents at the top, allowing the building to continually release heat. Provided that the fresh air inlet is located low in the building to allow cooler air to enter, the building will be cooled. This method of cooling is best suited for moderate climates or for the shoulder seasons (spring and fall) in seasonal climates. Nevertheless, the added benefit of reducing the cooling load for even a portion of the season helps conserve energy in the maintenance of the building.

Further techniques can lend themselves to the atrium's efficiency in passively moving air. With the addition of solar chimneys (fig. 1.60) or a system of collecting solar gain, the air stratification forces can be accentuated. Using the sun to heat



fig. 1.60 - Composite image of the solar chimney exterior (above); The west atrium ceiling opening for the solar chimney (below) at the York Computer Science Building



fig. 1.61 - York Computer Science Building



fig. 1.62 - Looking down into the east atrium from the third floor at the York Computer Science Building

up the air at the top of the atrium (or solar chimney atop the atrium) will increase the temperature differential and thereby increase the vertical pressure differential creating stronger convective flows. Or alternatively, simply by using the wind to induce convective flows, the air will move and cool the building. Air entering the windward side of a building is redirected to exit through the atrium top. Wind flowing over the top of a building creates a pressure differential, naturally drawing the air out of the exhaust vents. A negative pressure is created on the leeward side of the building, drawing air into and out of the atrium. These methods increase the air exchange rate, which provides more exhausting and cooling of the building and in turn strengthens the passive energy conservation.

In connection with the daylighting strategies, the collection of solar gain within an atrium is useful for preheating incoming fresh air. If the air is warmed up in this fashion and not allowed to be vented, the warmed air at the top of the atrium can be sent to the rest of the building. It is the rising of the warm air which allows for two things: it allows the fresh air to mix into the rest of the air as it rises, and secondly the stratification of the air allows only the warmed air at the top of the atrium to be taken and circulated throughout the rest of the building. This air strategy works in tandem with the daylighting strategy to reduce the amount of fresh air heating during the months where building heating is required in cold climates.

For an example of a building which has employed strategies of passive air movement, we can look at the York University Computer Science Building (fig. 1.61). Utilizing natural ventilation, the Computer Science building has no traditional duct work as the two atrium spaces help to capture heat stratification opportunities – a fundamental aspect of the ventilation strategy. Stratification is created differently in both atria. In the east atrium (fig. 1.62), the space rises four and a half storeys to establish the temperature differential, while the west atrium is two storeys high with the addition of two solar chimneys atop the atrium (fig. 1.60), using the combination of the atrium height and added solar gain to create the temperature differential.

The building's ventilation operates in two distinct modes. See fig. A.29 + A.30. In the *Spring/Fall* mode the building opens up and air flows through operable windows into the classrooms and offices passively. The air then migrates into the corridors which are interconnected with both atria. To help transfer the air between occupied office and computer lab spaces, while maintaining a certain level of privacy, inventive partitions were used (fig. 1.63). The air transferred to the atria

is released through high level openings. The atria also naturally draw cool air through the underground plenum to displace the exhausting air leaving the atria. Wind direction sensors control these openings in order to eliminate downdrafts. To extend the range of outdoor temperatures for which natural ventilation can be used, smoke exhaust fans can be run at half speed in order to assist in ventilating the space.<sup>52</sup>

In *Summer/Winter* mode the building is essentially “closed up” as mechanical systems are used to provide heating/cooling to the space. One air handler delivers fresh, tempered air to the atria space. Small local fancoil units on the perimeter of the spaces take the air from the atria, further condition it and deliver it to the occupied space. A second air handling unit serves the two basement lecture theatres and the large theatre via an underfloor supply system. The air is then partially released back into the atria, which serves as a mixing plenum for the fresh air delivered by the air handling unit and the return air from the classrooms, offices and theatres. The remainder of the air delivered by the fancoils is exhausted through the roof. The atria are indirectly conditioned by transferred air from the occupied space.<sup>53</sup>

See Appendix A.3 for further elaboration on the York University Computer Science Building.

Whether or not the designers of today are taking full advantage of these conservational atrium characteristics is yet to be determined. It is the further undertaking of this thesis to begin to identify which of these characteristics are prevalent in the built designs of the past few years and to assess the trends surrounding the atrium framed by our concerns and values in sustainable, conservational design.

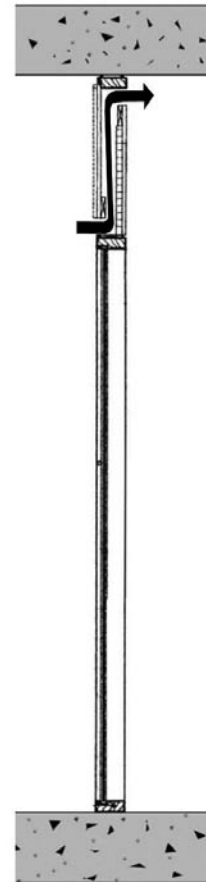


fig. 1.63 - Wall section drawing showing the air passage design to allow filtrating air to penetrate through.

## Endnotes

<sup>1</sup> Michael J. Bednar, *The New Atrium* (New York: McGraw-Hill, 1986), ix.

<sup>2</sup> John Fleming, Hugh Honour and Nikolaus Pevsner, *The Penguin Dictionary of Architecture*, 4th ed. (Harmondsworth: Penguin, 1991), 22.

<sup>3</sup> Answers.com, “Atrium: Definition, Synonyms and Much More,” <http://www.answers.com/topic/atrium> (12 January 2007).

<sup>4</sup> Wikipedia, “Atrium (architecture),” [http://en.wikipedia.org/wiki/Atrium\\_%28architecture%29](http://en.wikipedia.org/wiki/Atrium_%28architecture%29) (12 January 2007).

- <sup>5</sup> Richard Saxon, *Atrium Buildings : Development and Design* (London: The Architectural Press, 1983), 1.
- <sup>6</sup> Bednar, *The New Atrium*, ix
- <sup>7</sup> Ettore Camesasca, *History of the House. with a Foreword by Sir Robert Matthew. Translated by Isabel Quigly*, 1st American ed. (New York: Putnam, 1971), 32.
- <sup>8</sup> *ibid.*, 46
- <sup>9</sup> *ibid.*, 50
- <sup>10</sup> Vitruvius Pollio and Morris Hicky Morgan, *Vitruvius : The Ten Books on Architecture*. (New York: Dover Publications, 1960), 176-177.
- <sup>11</sup> The Columbia Electronic Encyclopedia, Sixth Edition, Columbia University Press., 2003., "Atrium," <http://www.answers.com/topic atrium?cat=biz-fin#copyright>
- <sup>12</sup> Bednar, *The New Atrium*, 6.
- <sup>13</sup> The Columbia Electronic Encyclopedia, Sixth Edition, Columbia University Press., 2003., *Atrium*
- <sup>14</sup> Bednar, *The New Atrium*, 7
- <sup>15</sup> Saxon, *Atrium Buildings: Development and Design*, 9-17.
- <sup>16</sup> Bednar, *The New Atrium*, 8-30.
- <sup>17</sup> *ibid.*, 8.
- <sup>18</sup> John Hix, *The Glass House* (London: Phaidon, 1974), 136.
- <sup>19</sup> Bednar, *The New Atrium*, 10
- <sup>20</sup> *ibid.*, 18-19
- <sup>21</sup> *ibid.*, 19
- <sup>22</sup> *ibid.*, 13-14
- <sup>23</sup> *ibid.*, 20-21
- <sup>24</sup> *ibid.*, 21
- <sup>25</sup> *ibid.*, 23
- <sup>26</sup> Richard Saxon, *The Atrium Comes of Age* (Harlow, Essex, England: Longman, 1994), 13.
- <sup>27</sup> Bednar, *The New Atrium*, 35-44
- <sup>28</sup> *ibid.*, 70-72
- <sup>29</sup> Saxon, *Atrium Buildings : Development and Design*, 35-42.
- <sup>30</sup> Bednar, *The New Atrium*, 81-84
- <sup>31</sup> Saxon, *Atrium Buildings : Development and Design*, 13
- <sup>32</sup> Bednar, *The New Atrium*, 25
- <sup>33</sup> Jennifer Taylor and John Andrews, *John Andrews : Architecture, a Performing Art* (New York: Oxford University Press, 1982), 58.
- <sup>34</sup> Saxon, *Atrium Buildings : Development and Design*, 14
- <sup>35</sup> *ibid.*, 14
- <sup>36</sup> *ibid.*, 15
- <sup>37</sup> Bednar, *The New Atrium*, 28
- <sup>38</sup> *ibid.*, 26
- <sup>39</sup> Saxon, *Atrium Buildings : Development and Design*, 15



- <sup>40</sup> Saxon, *The Atrium Comes of Age*, 3.
- <sup>41</sup> Saxon, *Atrium Buildings : Development and Design*, 74-75.
- <sup>42</sup> Bednar, *The New Atrium*, 64-65.
- <sup>43</sup> David R. Boyd, *Canada Vs. the OECD : An Environmental Comparison* (Victoria, B.C.: University of Victoria, Eco-Research Chair of Environmental Law & Policy, 2001), 16-17.
- <sup>44</sup> Government of Canada: Statistics Canada, "Report on Energy Supply-Demand in Canada 2003 = Bulletin Sur La Disponibilité Et Écoulement d'Énergie Au Canada 2003," (2004).
- <sup>45</sup> Government of Canada: Resources Canada, "Commercial and Institutional Consumption of Energy Survey (CICES)," <http://oee.rncan.gc.ca/Publications/statistics/cices05/section1.cfm?attr=0> (23 May 2006)
- <sup>46</sup> Government of Canada: Statistics Canada, *2003 Survey of Household Energy use (SHEU) : Detailed Statistical Report* (Ottawa: Office of Energy Efficiency, 2005), 46.
- <sup>47</sup> Whole Building Design Guide, "WBDG: Optimize Energy Use," [http://wbdg.org/design/minimize\\_consumption.php](http://wbdg.org/design/minimize_consumption.php) (25 May 2006)
- <sup>48</sup> Wikipedia, "World Population," <http://en.wikipedia.org/wiki/> (19 July 2006)
- <sup>49</sup> G.H. Brundtland (Chair), World Commission on Environment and Development, *Our Common Future* (Oxford: Oxford University Press, 1987), 383.
- <sup>50</sup> GreenBiz, "Sustainability in Architecture and Design: An Interview with Bert Gregory," [http://www.greenbiz.com/news/reviews\\_third.cfm?NewsID=26732](http://www.greenbiz.com/news/reviews_third.cfm?NewsID=26732) (15 June 2006)
- <sup>51</sup> Weekly Dose of Architecture, "Centennial HP Science and Technology Centre," <http://www.archidose.org/Feb06/022706.html> (10 February 2006).
- <sup>52</sup> David R. Macaulay and Jason F. McLennan, *The Ecological Engineer* (Kansas, MO: Ecotone Publishing, 2006), 151-160.
- <sup>53</sup> *ibid.*, 158



## **Part 2 :: Atrium Investigation**

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## Survey Preface

## 2.1

To analyse the trends of conservationism in our current atrium uses, a grouping of buildings was needed to create a database for analysis. Most importantly, the chosen grouping would have to offer easy access for visits and gathering information. The decision was made to examine institutional buildings in post-secondary public institutions of Southern Ontario. This selection was ideal for many of the reasons outlined below.

First, the time frame of the study attempts to reflect the onset of our cultural value resurgence in sustainability in North America. Starting in 2000, many 'green' buildings and designs had begun to be more prevalent within the architectural community. Concurrently, mainstream public awareness of the impending dangers of climate change was really beginning to take hold. Furthermore the establishment and implementation of certification systems and measures, such as LEED (Leadership in Energy and Environmental Design) and Green Globes were well on the way to making their first accreditations throughout Canada and the United States. Generally all this was beginning at the turn of the twenty first century and was an ideal place to start to see what the conserving tendencies in atria might be.

Secondly, the recent resurgence of growth in the post-secondary institutional sector allowed for a large pool of contemporary building examples to choose from. After thirty years of flat growth, new buildings were beginning to pop up all over campuses across Ontario; growth fuelled by the Progressive Conservative's Harris Government and its establishment of the Ontario SuperBuild Corporation in December 1999. SuperBuild's mandate was to act as a catalyst for the changes needed to ensure that Ontario maintains a first-class infrastructure in the

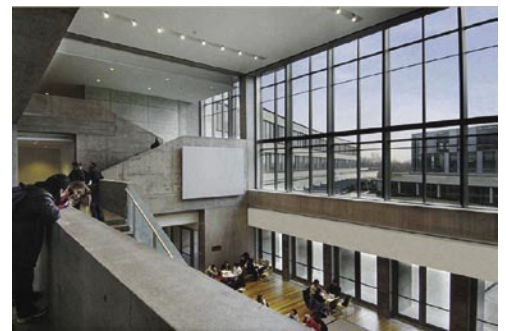


fig. 2.01 - The central atrium space at the Schulich School of Business building at York University is just one of over sixty atria documented in the survey of new academic buildings

fig. 2.02 - (opposite) Collage of academic buildings visited as part of the completed survey

21<sup>st</sup> century. It marks the largest investment in post-secondary education since the 1960s, as educational institutions were one of three major areas sited for delegation of capital assets to accomplish this goal.<sup>1</sup> Consequently, it offers a large set of new construction in a single sector of architectural building, very useful in creating this database.

Subsequently, with the new found capital, institutions were willing to seek out innovative and aspiring design solutions to their new building needs. This flexibility gave them a little freedom from cost related issues which enabled them to incorporate the latest in architectural design theory, materials and approaches. As these projects offer potential for more progressive thinking and leading architectural trends, they provide optimal grounds upon which to propose the assessment for current and future developments.

Again, with the generous budgets set forth by the government, it allowed for designs with innovation and flair, creating a high profile for many of these projects. As a result, a majority of these recent buildings have been well documented and published by their proud owners. Accessing the necessary information about these buildings has been made relatively simple, and assisted in the completeness of the database.

Furthermore, atria in public institutions are an offshoot of the initial and more standard atrium buildings such as office buildings, hotels and shopping centres. Thus this database is a good reflection of the current proliferation of atria designs. In fact, Ontario post-secondary institutions are home to some of the more complex and progressive atrium designs. These include: the York Computer Science Building, completed by Busby Architects; the Technology Wing at Sir Sandford Fleming College by LINE Architects; and the Centre for Cellular and Biomolecular Research at the University of Toronto by Behnisch Architekten, to name just a few.

Finally, as a necessity to compiling the database, site visits to all buildings surveyed were possible due to the close proximity of the buildings relative to the author. In addition, building access was easily accommodated as, being part of a public institution, these buildings were by their nature accessible, with the majority open to visitors.

Thus a broad survey of Southern Ontario's public Universities and Colleges was completed to assess new construction in this sector.<sup>2</sup> Buildings completed from 2000 till 2006 were used to maintain a current reference in the discussion surrounding the present and future trends of atria use. See Section 2.2 for an explanation of the survey criteria and the survey, Tables 2.1 – 2.8 in Section 2.3, to view the results of this search field.

A further catalogue of building images can be found in Appendix B; along with the name, size, and date of completion is a brief description of what is found within the building noting any inclusion of an atrium space. If there is such an atrium space, a brief description of the atrium's location and use is further noted.

## Survey Criteria Definitions

## 2.2

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### Basic Characteristics

*Year of Completion* – the year the building was completed

*Square Footage* – the approximate overall area of the building

*Number of Levels* – the overall number of levels in the building

*Atrium Space Present* – does the building include an atrium space of any size or form

*Atrium Height (levels)* – the number of levels the atrium rises within the building

*Full Building Height* – does the atrium rise the full height of the building; usually considered from ground level up

### Atrium Location

*Located Centrally* – the atrium is located within the building; completely surrounded by building

*Located on Perimeter* – is the atrium located somewhere on the perimeter of the building; the atrium has at least one exterior wall

### Organization + Circulation

*Building Hub* – a significant gathering space; often where vertical and horizontal circulation come together (although both circulations is not a requirement)

*Integrated Horizontal Circulation* – atrium which acts as a major hallway

*Includes Vertical Circulation* – a flight of stairs is a part of the atrium to link the floors which the atrium opens to

#### Conservation + Reuse

*Connective Adaptation* – the atrium was included during an addition to facilitate the connection where the two building segments meet

*Renovation Adaptation* – the atrium was included during a renovation where there was previously no atrium in the building

*Historical Preservation* – the atrium was used to help preserve or maintain an existing building, façade or historical building

*Diverse Space* – multi-function space; can be used or set-up for different functions: informal/formal gatherings, gallery, presentations, meeting space

*Future Reuse* – potential for the atrium space to change its program: with building renovation or change in building occupant or building use

#### Daylighting + Glazing Characteristics

*Daylighting* – incoming daylight reaches far enough to be useful; a subjective assessment by the author to say that at the very minimum, during some portion of the day incoming daylight reaches far enough to be useful, therefore potentially reducing the demand for electrical lighting

*Controlled Solar Gain* – attempt at controlling incoming daylight through the use of fritted glass, louvers, overhangs

*Top Glazing* – skylights; sawtooth skylights; light wells; glazing placed in the atrium ceiling



*Clerestory Glazing* – glazing within the atrium which is along the top portion of the walls of the upper most floor

*Vertical Glazing* – glazing within the atrium which is part of a wall

*North Facing* – glazing is on a north facing wall

*East Facing* – glazing is on an east facing wall

*South Facing* – glazing is on a south facing wall

*West Facing* – glazing is on a west facing wall

*Heliostats/Mirrors* – use of these directional aids to reflect daylight into the atrium space by compensating for the sun's movement and thus providing continuous illumination of the atrium space during the day

#### Air Handling Characteristics

*Passive Air Handling Strategy* – any air handling design strategy incorporated into the design of the atrium which decreases the use of electric fans for at least some time of the year

*Pre-conditioning Atrium* – fresh air is pre-heated (or mixed) using the volume of the atrium; preheating is accomplished by incoming daylight

*Exhaust/Cooling Atrium* – used (warm) air is collected and let out of the building through vents at the top of the atrium; similarly achieved for ventilation and/or cooling

*Solar Chimney* – use of vertical shafts atop the atrium which utilize solar energy to enhance the natural stack effect (or air buoyancy) which assist venting of the atrium space

## Green Perspective

*Self Proclaimed 'Green'* – do the designers of the building consider the building to have 'green' and or sustainable qualities

*LEED Certified* – has the building been LEED (Leadership in Energy and Environmental Design) certified to be acknowledged by the Canada Green Building Council

## Generic Atrium Forms

*Refer back to Section 1.4*

## Academic Building Survey

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## 2.3

Table 2.1 - Buildings Completed in 2000	Insert 58 - A
Table 2.2 - Buildings Completed in 2001	Insert 58 - B
Table 2.3 - Buildings Completed in 2002	Insert 58 - C
Table 2.4 - Buildings Completed in 2003	Insert 58 - D
Table 2.5 - Buildings Completed in 2004	Insert 58 - E
Table 2.6 - Buildings Completed in 2005	Insert 58 - F
Table 2.7 - Buildings Completed in 2006	Insert 58 - G
Table 2.8 - Annual Totals Comparison	Insert 58 - H



Catalogue #	B.001	B.008	B.024	B.049	B.057	
Building Name	Police and Public Safety Institute	The Minto Center for Engineering Studies Addition	Institute for Applied Health Studies Mohawk / McMaster	Sheridan Centre for Animation and Emerging Technologies (SCAET)	Access to Opportunities Program Building (ATOP)	2000 Totals
Institution	Algonquin College	Carleton University	McMaster University	Sheridan College	University of Guelph	5 Buildings
Year of Completion	2000	2000	2000	2000	2000	
Square Footage	93,885 sqft	42,632 sqft	168,000 sqft	91,000 sqft	40,500 sqft	
Number of Levels	3.0 levels	3.0 additional	5.0 levels	3.0 levels	2.0 levels	
Atrium Space Present	1	0	1	1	1	4
Atrium Height (levels)	2.0 levels	n/a	5.0 levels	3.0 levels	2.0 levels	
Full Building Height	0	n/a	1	1	1	3
Category of Atrium Form	Partial 1 Sided	n/a	1 Sided	Multi-Lateral Clsd + 3S	Linear	
Located Centrally	0	n/a	0	1	1	2
Located on Perimeter	1	n/a	1	1	0	3
Closed Atrium	0	n/a	0	0	0	0
1 Sided Atrium	0	n/a	1	0	1	2
2 Sided Atrium	0	n/a	0	0	0	0
3 Sided Atrium	0	n/a	0	0	0	0
Linear Atrium	0	n/a	0	0	0	0
Partial	1	n/a	0	0	0	1
Bridging Atrium	0	n/a	0	0	0	0
Podium Atrium	0	n/a	0	0	0	0
Multi-Lateral Atrium	0	n/a	0	1	0	1
Multi-Vertical Atrium	0	n/a	0	0	0	0
Integrated Horizontal Circ	0	n/a	0	1	1	2
Includes Vertical Circ	0	n/a	1	1	1	3
Building Hub	0	n/a	1	1	0	2
Connection Adaptation	0	n/a	0	0	0	0
Renovation Adaptation	0	n/a	0	0	0	0
Historical Preservation	0	n/a	0	0	0	0
Diverse Space	0	n/a	1	1	0	2
Future Reuse	0	n/a	0	0	0	0
Daylighting	1	n/a	1	1	1	4
Controlled Solar Gain	0	n/a	0	0	0	0
Top Glazing	0	n/a	0	1	1	2
Clerestory Glazing	0	n/a	0	0	0	0
Vertical Glazing	1	n/a	1	1	1	4
North Facing	0	n/a	1	1	0	2
East Facing	0	n/a	0	1	0	1
South Facing	1	n/a	0	0	1	2
West Facing	0	n/a	0	1	0	1
Mirror Assist/ Heliostats	0	n/a	0	0	0	0
Passive Air Handling Strategy	0	n/a	0	0	0	0
Pre-Conditioning Atrium	0	n/a	0	0	0	0
Exhaust/Cooling Atrium	0	n/a	0	0	0	0
Use of Solar Chimney	0	n/a	0	0	0	0
Self Proclaimed Green	0	0	0	0	0	0
LEED Certified	0	0	0	0	0	0

Table 2.1

2000

Catalogue #	B.004	B.005	B.050	B.069	B.092	B.099	
Building Name	ScotiaBank Hall	South Block	Sheldon Levy Centre CCIT Building	The John and Edna Davenport Chemical Research Building	St. Michael's Campus	Computer Science Building	2001 Totals
Institution	Brock University	Brock University	Sheridan College	University of Toronto	Wilfred Laurier University	York University	6 Buildings
Year of Completion	2001	2001	2001	2001	2001	2001	
Square Footage	29,496 sqft	80,083 sqft	65,000 sqft	110,000 sqft	20,441 sqft	102,250 sqft	
Number of Levels	3.0 levels	2.5 levels	3.0 levels	2.0 additional	1.0 levels	4.0 levels	
Atrium Space Present	0	1	1	1	0	1	4
Atrium Height (levels)	n/a	2.5 levels	2.0 levels	2.0 levels	n/a	4.0 levels	
Full Building Height	n/a	1	0	0	n/a	1	2
Category of Atrium Form	n/a	1 Sided	Partial 1 Sided	Parital Closed	n/a	Multi-lateral Clsd + Linear	
Located Centrally	n/a	0	0	1	n/a	1	2
Located on Perimeter	n/a	1	1	0	n/a	0	2
Closed Atrium	n/a	0	0	0	n/a	0	0
1 Sided Atrium	n/a	1	0	0	n/a	0	1
2 Sided Atrium	n/a	0	0	0	n/a	0	0
3 Sided Atrium	n/a	0	0	0	n/a	0	0
Linear Atrium	n/a	0	0	0	n/a	0	0
Partial	n/a	0	1	1	n/a	0	2
Bridging Atrium	n/a	0	0	0	n/a	0	0
Podium Atrium	n/a	0	0	0	n/a	0	0
Multi-Lateral Atrium	n/a	0	0	0	n/a	1	1
Multi-Vertical Atrium	n/a	0	0	0	n/a	0	0
Integrated Horizontal Circ	n/a	1	1	0	n/a	1	3
Includes Vertical Circ	n/a	1	1	0	n/a	0	2
Building Hub	n/a	1	1	0	n/a	0	2
Connection Adaptation	n/a	0	0	1	n/a	0	1
Renovation Adaptation	n/a	0	0	0	n/a	0	0
Historical Preservation	n/a	0	0	0	n/a	0	0
Diverse Space	n/a	1	0	1	n/a	0	2
Future Reuse	n/a	1	0	1	n/a	1	3
Daylighting	n/a	1	1	1	n/a	1	4
Controlled Solar Gain	n/a	0	0	0	n/a	1	1
Top Glazing	n/a	1	1	1	n/a	1	4
Clerestory Glazing	n/a	1	1	0	n/a	0	2
Vertical Glazing	n/a	1	1	0	n/a	1	3
North Facing	n/a	0	1	0	n/a	0	1
East Facing	n/a	0	0	0	n/a	0	0
South Facing	n/a	1	1	0	n/a	1	3
West Facing	n/a	0	0	0	n/a	0	0
Mirror Assist/ Heliostats	n/a	0	0	0	n/a	0	0
Passive Air Handling Strategy	n/a	0	0	0	n/a	1	1
Pre-Conditioning Atrium	n/a	0	0	0	n/a	0	0
Exhaust/Cooling Atrium	n/a	0	0	0	n/a	1	1
Use of Solar Chimney	n/a	0	0	0	n/a	1	1
Self Proclaimed Green	0	0	0	0	0	1	1
LEED Certified	0	0	0	0	0	0	0

Catalogue #	B.002	B.009	B.010	B.011	B.012	B.015	B.016	B.025	B.033	B.034	B.039	B.058	B.065	B.070	B.071	B.079	B.083	B.093	B.094		Catalogue #
Building Name	School of Advanced Technology	Azrieli Pavilion	Azrieli Theatre	National Wildlife Research Centre at the Nesbitt Building	H.M. Tory Building	E Wing	Communication Arts Building 'M' Building	AIC Wing School of Business Expansion	Chernoff Hall	Goodes Hall	Sally Horsfall Eaton Centre for Studies in Community Health	Rozanski Hall	School of Information Technology and Engineering (SITE)	Bahen Centre for Information Technology	Centre for Applied Bioscience and Biotechnology	William M. Tatham Centre for Co-operative Education and Career Services	Lawrence National Centre for Policy and Management	Arts C Wing Addition	Schlegel Building	2002 Totals	Building Name
Institution	Algonquin College	Carleton University	Carleton University	Carleton University	Carleton University	Conestoga College	Fanshawe College	McMaster University	Queen's University	Queen's University	Ryerson University	University of Guelph	University of Ottawa	University of Toronto	University of Toronto Miss.	University of Waterloo	University of Western Ontario	Wilfred Laurier University	Wilfred Laurier University	19 Buildings	Institution
Year of Completion	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002	2002		Year of Completion
Square Footage	116,000 sqft	35,000 sqft	40,000 sqft	60,000 sqft	80,000 sqft	115,000 sqft	91,414 sqft	22,000 *	147,000 sqft	112,805 sqft	72,000 sqft	76,700 sqft	180,000 sqft	400,000 sqft	9,200 sqft	45,500 sqft	18,000 sqft	29,558 sqft	39,472 sqft		Square Footage
Number of Levels	3.0 levels	4.0 levels	4.0 levels	4.0 levels	3.0 levels	3.0 levels	3.0 levels	3.0 levels	5.0 levels	2.5 levels	2.0 additional	1.0 level	6.0 levels	8.0 levels	3.0 levels	4.0 levels	3.0 levels	4.0 levels	3.0 levels		Number of Levels
Atrium Space Present	1	0	1	0	0	1	0	0	1	1	0	1	1	1	0	0	1	0	1	10	Atrium Space Present
Atrium Height (levels)	3.0 levels	n/a	2.0 levels	n/a	n/a	2.0 levels	n/a	n/a	5.0 levels	2.5 levels	n/a	1.0 level	6.0 levels	8.0 levels	n/a	n/a	3.0 levels	n/a	3.0 levels		Atrium Height (levels)
Full Building Height	1	n/a	0	n/a	n/a	0	0	0	1	1	n/a	1	1	1	n/a	n/a	1	n/a	1	8	Full Building Height
Category of Atrium Form	Partial Closed	n/a	Partial 2 Sided	n/a	n/a	2 Sided	n/a	n/a	Partial 1 Sided	Bridging	n/a	1 Sided	1 Sided	Linear	n/a	n/a	1 Sided	n/a	Closed		Category of Atrium Form
Located Centrally	1	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	0	0	1	n/a	n/a	0	n/a	1	4	Located Centrally
Located on Perimeter	0	n/a	1	n/a	n/a	1	n/a	n/a	1	0	n/a	1	1	0	n/a	n/a	1	n/a	0	6	Located on Perimeter
Closed Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	1	1	Closed Atrium
1 Sided Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	1	1	0	n/a	n/a	1	n/a	0	3	1 Sided Atrium
2 Sided Atrium	0	n/a	0	n/a	n/a	1	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	1	2 Sided Atrium
3 Sided Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	3 Sided Atrium
Linear Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	1	n/a	n/a	0	n/a	0	1	Linear Atrium
Partial	1	n/a	1	n/a	n/a	0	n/a	n/a	1	0	n/a	0	0	0	n/a	n/a	0	n/a	0	3	Partial
Bridging Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	0	0	0	n/a	n/a	0	n/a	0	1	Bridging Atrium
Podium Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Podium Atrium
Multi-Lateral Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Multi-Lateral Atrium
Multi-Vertical Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Multi-Vertical Atrium
Integrated Horizontal Circ	0	n/a	1	n/a	n/a	1	n/a	n/a	0	1	n/a	1	1	1	n/a	n/a	0	n/a	0	6	Integrated Horizontal Circ
Includes Vertical Circ	1	n/a	0	n/a	n/a	1	n/a	n/a	1	1	n/a	n/a	1	1	n/a	n/a	1	n/a	1	8	Includes Vertical Circ
Building Hub	1	n/a	0	n/a	n/a	1	n/a	n/a	1	1	n/a	1	1	1	n/a	n/a	1	n/a	1	9	Building Hub
Connection Adaptation	0	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	0	0	0	n/a	n/a	1	n/a	0	2	Connection Adaptation
Renovation Adaptation	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Renovation Adaptation
Historical Preservation	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	1	n/a	0	1	Historical Preservation
Diverse Space	0	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	1	1	1	n/a	n/a	1	n/a	1	6	Diverse Space
Future Reuse	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Future Reuse
Daylighting	1	n/a	1	n/a	n/a	1	n/a	n/a	1	1	n/a	1	1	1	n/a	n/a	1	n/a	1	10	Daylighting
Controlled Solar Gain	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	1	n/a	n/a	1	n/a	0	2	Controlled Solar Gain
Top Glazing	0	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	1	0	1	n/a	n/a	0	n/a	1	4	Top Glazing
Clerestory Glazing	1	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	1	Clerestory Glazing
Vertical Glazing	0	n/a	1	n/a	n/a	1	n/a	n/a	1	1	n/a	1	1	1	n/a	n/a	1	n/a	0	8	Vertical Glazing
North Facing	1	n/a	1	n/a	n/a	1	n/a	n/a	0	1	n/a	0	0	0	n/a	n/a	1	n/a	0	5	North Facing
East Facing	1	n/a	0	n/a	n/a	0	n/a	n/a	1	0	n/a	0	0	1	n/a	n/a	0	n/a	0	3	East Facing
South Facing	1	n/a	0	n/a	n/a	0	n/a	n/a	0	1	n/a	0	0	0	n/a	n/a	0	n/a	0	2	South Facing
West Facing	0	n/a	1	n/a	n/a	1	n/a	n/a	0	0	n/a	1	1	1	n/a	n/a	0	n/a	0	5	West Facing
Mirror Assist/ Heliostats	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Mirror Assist/ Heliostats
Passive Air Handling Strategy	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	1	1	n/a	n/a	0	n/a	0	2	Passive Air Handling Strategy
Pre-Conditioning Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	1	0	n/a	n/a	0	n/a	0	1	Pre-Conditioning Atrium
Exhaust/Cooling Atrium	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	1	n/a	n/a	0	n/a	0	1	Exhaust/Cooling Atrium
Use of Solar Chimney	0	n/a	0	n/a	n/a	0	n/a	n/a	0	0	n/a	0	0	0	n/a	n/a	0	n/a	0	0	Use of Solar Chimney
Self Proclaimed Green	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3	Self Proclaimed Green
LEED Certified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	LEED Certified

Catalogue #	B.006	B.014	B.017	B.019	B.020	B.021	B.025	B.035	B.040	B.044	B.046	B.052	B.054	B.063	B.066	B.072	B.080	B.084	B.085	B.086	B.100	B.101		Catalogue #
Building Name	East Academic	HP Science and Technology Center	F' Building West Addition	146 Kendal Avenue Casa Loma Campus	Centre for Financial Services Education	Centre for Technology Enhanced Learning	Arthur Bourns Building Addition	Cancer Research Institute	The Heidelberg Centre	Ford Centre for Excellence in Manufacturing	School of Business Newnham Campus Addition	Technology Wing Southerland Campus	Chemical Sciences Building	Science Building	Biology Building	Sidney Smith Infill Project	Centre for Environmental and Information Technology (CEIT)	Elizabeth A. Labatt Hall King's College Campus	Spencer Engineering Building Addition	Thompson Engineering Building	Schulich School of Business	TEL Building	2003 Totals	Building Name
Institution	Brock University	Centennial College	Fanshawe College	George Brown College	George Brown College	Georgian College	McMaster University	Queen's University	Ryerson University	St. Clair College	Seneca College	Sir Sandford College	Trent University	University of Ontario	University of Ottawa	University of Toronto	University of Waterloo	University of Western Ontario	University of Western Ontario	University of Western Ontario	York University	York University	22 Buildings	Institution
Year of Completion	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003		Year of Completion
Square Footage	7,262 sqft	237,000 sqft	51,210 sqft	118,000 sqft	48,000 sqft	100,000 sqft	30,000 sqft	46,015 sqft	30,000 sqft	120,000 sqft	50,000 sqft	50,000 sqft	45,000 sqft	214,374 sqft	56,000 sqft	6,150 sqft	164,680 sqft	65,000 sqft*	20,000 sqft	99,000 sqft	250,000 sqft	360,000 sqft		Square Footage
Number of Levels	1.0 level	4.0 levels	3.0 levels	4.0 levels	5.0 levels	3.0 levels	4.0 levels	4.0 levels	3.0 levels	2.0 levels	3.0 levels	2.5 levels	1.5 levels	4.0 levels	4.0 levels	3.0 levels	4.0 levels	2.0 levels	2.0 levels	4.0 levels	3.0 levels	5.0 levels		Number of Levels
Atrium Space Present	0	1	0	1	0	1	0	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	15	Atrium Space Present
Atrium Height (levels)	n/a	4.0 levels	n/a	4.0 levels	n/a	2.0 levels	n/a	3.0 levels	n/a	2.0 levels	3.0 levels	2.5 levels	1.5 levels	4.0 levels	n/a	2.0 levels	3.5 levels	2.0 levels	n/a	2.0 levels	3.0 levels	5.0 levels		Atrium Height (levels)
Full Building Height	n/a	1	n/a	1	n/a	0	n/a	0	n/a	1	1	1	1	1	n/a	0	1	1	n/a	0	1	1	11	Full Building Height
Category of Atrium Form	n/a	Multi-Lateral Closed	n/a	Multi-Lateral 1 Sided	n/a	Partial 1 Sided	n/a	Partial 1 Sided	n/a	Partial 2 Sided	Partial Closed	Linear	Partial 3 Sided	Multi-Lateral Closed	n/a	Closed	Closed	Partial Closed	n/a	Partial Linear	Partial 1 Sided	Multi-Lateral Lnr + Clsd + 1S		Category of Atrium Form
Located Centrally	n/a	1	n/a	0	n/a	0	n/a	0	n/a	0	1	1	0	1	n/a	1	1	1	n/a	1	0	1	9	Located Centrally
Located on Perimeter	n/a	0	n/a	1	n/a	1	n/a	1	n/a	1	0	0	1	0	n/a	0	0	0	n/a	0	1	1	7	Located on Perimeter
Closed Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	1	1	0	n/a	0	0	0	2	Closed Atrium
1 Sided Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	1 Sided Atrium
2 Sided Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	2 Sided Atrium
3 Sided Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	3 Sided Atrium
Linear Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	0	n/a	0	0	0	n/a	0	0	0	1	Linear Atrium
Partial	n/a	0	n/a	0	n/a	1	n/a	1	n/a	1	1	0	1	0	n/a	0	0	1	n/a	1	1	0	8	Partial
Bridging Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Bridging Atrium
Podium Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Podium Atrium
Multi-Lateral Atrium	n/a	1	n/a	1	n/a	0	n/a	0	n/a	0	0	0	0	1	n/a	0	0	0	n/a	0	0	1	4	Multi-Lateral Atrium
Multi-Vertical Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Multi-Vertical Atrium
Integrated Horizontal Circ	n/a	1	n/a	1	n/a	0	n/a	0	n/a	0	0	1	1	1	n/a	1	1	1	n/a	1	0	1	10	Integrated Horizontal Circ
Includes Vertical Circ	n/a	0	n/a	1	n/a	1	n/a	0	n/a	1	0	0	0	1	n/a	0	1	0	n/a	0	1	1	7	Includes Vertical Circ
Building Hub	n/a	1	n/a	0	n/a	1	n/a	0	n/a	1	0	1	0	1	n/a	1	1	1	n/a	0	1	1	10	Building Hub
Connection Adaptation	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	1	0	0	n/a	0	0	0	1	Connection Adaptation
Renovation Adaptation	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Renovation Adaptation
Historical Preservation	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Historical Preservation
Diverse Space	n/a	1	n/a	0	n/a	0	n/a	1	n/a	1	1	1	0	1	n/a	1	1	1	n/a	0	1	1	10	Diverse Space
Future Reuse	n/a	1	n/a	0	n/a	0	n/a	1	n/a	0	1	0	0	0	n/a	0	0	0	n/a	0	0	0	3	Future Reuse
Daylighting	n/a	1	n/a	1	n/a	1	n/a	1	n/a	1	1	1	1	1	n/a	0	1	1	n/a	1	1	1	14	Daylighting
Controlled Solar Gain	n/a	1	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	1	n/a	0	0	0	n/a	0	0	1	4	Controlled Solar Gain
Top Glazing	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	1	n/a	0	1	1	n/a	0	1	1	6	Top Glazing
Clerestory Glazing	n/a	1	n/a	0	n/a	0	n/a	0	n/a	1	1	1	1	1	n/a	0	1	1	n/a	0	0	1	9	Clerestory Glazing
Vertical Glazing	n/a	0	n/a	1	n/a	1	n/a	1	n/a	1	1	0	1	1	0	n/a	1	0	0	n/a	1	1	10	Vertical Glazing
North Facing	n/a	1	n/a	1	n/a	1	n/a	0	n/a	0	1	1	1	1	n/a	0	0	0	n/a	0	0	1	8	North Facing
East Facing	n/a	1	n/a	1	n/a	0	n/a	1	n/a	1	1	1	1	0	1	n/a	1	0	0	n/a	1	1	11	East Facing
South Facing	n/a	1	n/a	0	n/a	0	n/a	0	n/a	1	1	1	1	0	n/a	0	0	1	n/a	0	0	0	6	South Facing
West Facing	n/a	1	n/a	0	n/a	0	n/a	0	n/a	1	1	0	1	0	n/a	1	1	0	n/a	1	0	1	8	West Facing
Mirror Assist/ Heliostats	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Mirror Assist/ Heliostats
Passive Air Handling Strategy	n/a	1	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	1	n/a	0	0	0	n/a	0	0	1	4	Passive Air Handling Strategy
Pre-Conditioning Atrium	n/a	0	n/a	0	n/a	0	n/a	0	n/a	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	Pre-Conditioning Atrium
Exhaust/Cooling Atrium	n/a	1	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	1	n/a	0	0	0	n/a	0	0	1	4	Exhaust/Cooling Atrium
Use of Solar Chimney	n/a	1	n/a	0	n/a	0	n/a	0	n/a	0	0	1	0	0	n/a	0	0	0	n/a	0	0	0	2	Use of Solar Chimney
Self Proclaimed Green	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1	6	Self Proclaimed Green
LEED Certified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	LEED Certified



Catalogue #	B.003	B.013	B.022	B.023	B.027	B.028	B.030	B.031	B.032	B.036	B.041	B.045	B.047	B.053	B.055	B.061	B.064	B.073	B.074	B.081	B.087	B.090	B.091	B.095	B.096	B.097	B.102	Catalogue #	
Building Name	Transportation Technology Centre	Nesbitt Biology Building Addition	Computer Technology Centre Lakeshore Campus Building 'F'	University of Guelph-Humber Building @ North Campus Humber	Information Technology Building Expansion	James Stewart Center for Mathematics	Information Technology Centre	Niagara Culinary Institute	Sharp Centre for Design/ 100 McCaul Street Main Building	Beamish Munro Hall \ Integrated Learning Centre	The George Vari Engineering and Computing Centre	Link Building (Grey Wing)	Animal Health Facility King Campus	School of Environmental and Natural Resource Sciences Frost Campus	Peter Gzowski College	Science Complex Phase 1	Business and IT Building	Management Building	School of Continuing Studies	School of Architecture	Arthur and Sonia Labatt Health Sciences Building	Jackman Dramatic Art Centre	Anthony P. Toldo Health Education + Learning Centre	Bricker Academic Building	Odeon, Brantford Campus	Science Research Centre	Executive Learning Centre (Schulich School of Business)	2004 Totals	Building Name
Institution	Algonquin College	Carleton University	Humber College	Humber College	McMaster University	McMaster University	Mohawk College	Niagara College	Ontario College of Art + Design	Queen's University	Ryerson University	St. Lawrence College	Seneca College	Sir Sandford College	Trent University	University of Guelph	University of Ontario	University of Toronto - Scarb	University of Toronto	University of Waterloo	University of Western Ontario	University of Windsor	University of Windsor	Wilfred Laurier University	Wilfred Laurier University	Wilfred Laurier University	York University	27 Buildings	Institution
Year of Completion	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004		Year of Completion
Square Footage	32,000 sqft	5,000 sqft	45,000 sqft	133,130 sqft	36,000 sqft	49,000 sqft	60,000 sqft	40,000 sqft	181,860 sqft	100,000 sqft	225,000 sqft	75,000 sqft	26,000 sqft	42,000 sqft	207,600 sqft	170,000 sqft	104,614 sqft	47,000 sqft	18,800 sqft	85,000 sqft	78,000 sqft	34,700 sqft	66,400 sqft	71,022 sqft	22,372 sqft	43,000 sqft	80,000 sqft		Square Footage
Number of Levels	1.0 level	1.0 additional	3.0 levels	4.0 levels	4.0 levels	4.0 levels	2.0 levels	1.0 level	6.0 levels*	3.0 levels	4.0 levels	2.0 levels	1.0 level	1.0 level	2 + 4 levels**	5.0 levels	4.0 levels	3.0 levels	4.0 levels	3.0 levels	4.0 levels	2.0 levels	3.0 levels	5.0 levels	2.0 levels	4.0 levels	12.0 levels		Number of Levels
Atrium Space Present	0	0	0	1	0	1	1	0	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	16	Atrium Space Present
Atrium Height (levels)	n/a	n/a	n/a	4.0 levels	n/a	4.0 levels	2.0 levels	n/a	4.0 levels	3.0 levels	3.0 levels	2.0 levels	n/a	1.0 level	n/a	n/a	4.0 levels	3.0 levels	2.0 levels	3.0 levels	2.0 levels	2.0 levels	3.0 levels	2.0 levels	n/a	n/a	n/a		Atrium Height (levels)
Full Building Height	n/a	n/a	n/a	1	n/a	1	1	n/a	1	1	0	1	n/a	1	n/a	n/a	1	1	0	1	1	0	1	0	n/a	n/a	n/a	12	Full Building Height
Category of Atrium Form	n/a	n/a	n/a	Multi-Lateral Closed	n/a	Multi-Lateral Closed	Multi-Lateral 1 S + Closed	n/a	Partial 1 Sided	Closed	Partial Closed	Partial Closed	n/a	Linear	n/a	n/a	Closed	Linear	Partial 3 Sided	Partial Linear	Partial 1 Sided	Linear	Linear	Partial Closed	n/a	n/a	n/a		Category of Atrium Form
Located Centrally	n/a	n/a	n/a	1	n/a	1	1	n/a	0	1	1	1	n/a	1	n/a	n/a	1	1	0	1	0	1	1	1	n/a	n/a	n/a	13	Located Centrally
Located on Perimeter	n/a	n/a	n/a	0	n/a	0	1	n/a	1	0	0	0	n/a	0	n/a	n/a	0	0	1	0	1	0	0	0	n/a	n/a	n/a	4	Located on Perimeter
Closed Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	1	0	0	n/a	0	n/a	n/a	1	0	0	0	0	0	0	0	n/a	n/a	n/a	2	Closed Atrium
1 Sided Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	1 Sided Atrium
2 Sided Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	2 Sided Atrium
3 Sided Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	3 Sided Atrium
Linear Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	1	n/a	n/a	0	1	0	0	0	1	0	n/a	n/a	n/a	n/a	4	Linear Atrium
Partial	n/a	n/a	n/a	0	n/a	0	0	n/a	1	0	1	1	n/a	0	n/a	n/a	0	0	1	1	1	0	1	1	n/a	n/a	n/a	7	Partial
Bridging Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Bridging Atrium
Podium Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Podium Atrium
Multi-Lateral Atrium	n/a	n/a	n/a	1	n/a	1	1	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	3	Multi-Lateral Atrium
Multi-Vertical Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Multi-Vertical Atrium
Integrated Horizontal Circ	n/a	n/a	n/a	0	n/a	0	1	n/a	0	0	0	1	n/a	1	n/a	n/a	0	1	0	1	0	0	1	1	n/a	n/a	n/a	7	Integrated Horizontal Circ
Includes Vertical Circ	n/a	n/a	n/a	1	n/a	0	1	n/a	1	1	0	1	n/a	0	n/a	n/a	1	1	0	1	1	1	0	0	n/a	n/a	n/a	10	Includes Vertical Circ
Building Hub	n/a	n/a	n/a	1	n/a	0	1	n/a	1	1	0	1	n/a	0	n/a	n/a	1	1	1	0	1	1	1	1	n/a	n/a	n/a	11	Building Hub
Connection Adaptation	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Connection Adaptation
Renovation Adaptation	n/a	n/a	n/a	0	n/a	1	0	n/a	1	0	0	0	n/a	0	n/a	n/a	0	0	1	1	0	0	0	0	n/a	n/a	n/a	4	Renovation Adaptation
Historical Preservation	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Historical Preservation
Diverse Space	n/a	n/a	n/a	1	n/a	0	1	n/a	1	1	1	1	0	n/a	0	n/a	n/a	1	1	1	1	0	1	0	n/a	n/a	n/a	10	Diverse Space
Future Reuse	n/a	n/a	n/a	0	n/a	0	1	n/a	0	1	0	0	n/a	0	n/a	n/a	0	0	1	0	0	0	0	0	n/a	n/a	n/a	3	Future Reuse
Daylighting	n/a	n/a	n/a	1	n/a	1	1	n/a	1	1	1	1	n/a	1	n/a	n/a	1	1	1	1	1	1	1	0	n/a	n/a	n/a	15	Daylighting
Controlled Solar Gain	n/a	n/a	n/a	0	n/a	0	0	n/a	0	1	1	0	n/a	1	n/a	n/a	1	1	1	0	0	0	0	0	n/a	n/a	n/a	6	Controlled Solar Gain
Top Glazing	n/a	n/a	n/a	1	n/a	1	1	n/a	0	1	1	1	n/a	1	n/a	n/a	1	1	0	0	1	1	0	0	n/a	n/a	n/a	11	Top Glazing
Clerestory Glazing	n/a	n/a	n/a	1	n/a	0	1	n/a	0	1	0	0	n/a	1	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	4	Clerestory Glazing
Vertical Glazing	n/a	n/a	n/a	0	n/a	0	1	n/a	1	0	0	0	n/a	0	n/a	n/a	0	1	1	1	1	1	1	1	n/a	n/a	n/a	9	Vertical Glazing
North Facing	n/a	n/a	n/a	0	n/a	0	1	n/a	0	0	0	0	n/a	1	n/a	n/a	0	0	1	0	0	1	0	1	n/a	n/a	n/a	5	North Facing
East Facing	n/a	n/a	n/a	1	n/a	0	1	n/a	1	0	0	0	n/a	0	n/a	n/a	0	0	1	1	0	0	0	0	n/a	n/a	n/a	5	East Facing
South Facing	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	1	0	1	0	0	1	n/a	n/a	n/a	3	South Facing
West Facing	n/a	n/a	n/a	1	n/a	0	1	n/a	0	1	0	0	n/a	0	n/a	n/a	0	1	0	1	0	0	1	0	n/a	n/a	n/a	6	West Facing
Mirror Assist/ Heliostats	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Mirror Assist/ Heliostats
Passive Air Handling Strategy	n/a	n/a	n/a	0	n/a	0	0	n/a	0	1	0	0	n/a	1	n/a	n/a	1	0	0	0	0	0	0	0	n/a	n/a	n/a	3	Passive Air Handling Strategy
Pre-Conditioning Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Pre-Conditioning Atrium
Exhaust/Cooling Atrium	n/a	n/a	n/a	0	n/a	0	0	n/a	0	1	0	0	n/a	1	n/a	n/a	1	0	0	0	0	0	0	0	n/a	n/a	n/a	3	Exhaust/Cooling Atrium
Use of Solar Chimney	n/a	n/a	n/a	0	n/a	0	0	n/a	0	0	0	0	n/a	0	n/a	n/a	0	0	0	0	0	0	0	0	n/a	n/a	n/a	0	Use of Solar Chimney
Self Proclaimed Green	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	4	Self Proclaimed Green
LEED Certified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	LEED Certified

Catalogue #	B.029	B.042	B.048	B.051	B.067	B.075	B.076	B.082	B.088	
Building Name	Michael G. DeGroote Centre for Learning and Discovery (MDCL)	Heaslip House	Markham Campus	Centre for Manufacturing and Design Technologies	Biosciences Complex	Arts & Administration Building	The Terrence Donnelly Centre for Cellular and Biomolecular Research (CCBR)	Lyle S. Hallman Institue for Health Promotion	North Campus Building	2005 Totals
Institution	McMaster University	Ryerson University	Seneca College	Sheridan College	University of Ottawa	University of Toronto - Scarb	University of Toronto	University of Waterloo	University of Western Ontario	9 Buildings
Year of Completion	2005	2005	2005	2005	2005	2005	2005	2005	2005	
Square Footage	275,000 sqft	42,000 sqft	256,000 sqft	18,000 sqft	190,000 sqft	55,000 sqft	221,120 sqft	24,780 sqft	114,000 sqft	
Number of Levels	5.0 levels	7.0 levels	10.0 levels	2.0 levels	5.0 levels	4.0 levels	10.0 levels	3.0 levels	4.0 levels	
Atrium Space Present	1	0	1	1	0	0	1	0	1	5
Atrium Height (levels)	3.0 levels	n/a	4.0 levels	2.0 levels	n/a	n/a	4.0 levels	n/a	4.0 levels	
Full Building Height	0	n/a	0	1	n/a	n/a	0	n/a	1	2
Category of Atrium Form	Partial 3 Sided	n/a	Partial 1 Sided	Linear	n/a	n/a	Multi-Vertical Clsd + 1S	n/a	Linear	
Located Centrally	0	n/a	0	1	n/a	n/a	1	n/a	1	3
Located on Perimeter	1	n/a	1	0	n/a	n/a	1	n/a	0	3
Closed Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
1 Sided Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
2 Sided Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
3 Sided Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Linear Atrium	0	n/a	0	1	n/a	n/a	0	n/a	1	2
Partial	1	n/a	1	0	n/a	n/a	0	n/a	0	2
Bridging Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Podium Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Multi-Lateral Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Multi-Vertical Atrium	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Integrated Horizontal Circ	0	n/a	0	1	n/a	n/a	0	n/a	1	2
Includes Vertical Circ	0	n/a	1	1	n/a	n/a	1	n/a	1	4
Building Hub	0	n/a	1	1	n/a	n/a	0	n/a	1	3
Connection Adaptation	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Renovation Adaptation	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Historical Preservation	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Diverse Space	1	n/a	1	0	n/a	n/a	1	n/a	1	4
Future Reuse	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Daylighting	1	n/a	1	1	n/a	n/a	1	n/a	1	5
Controlled Solar Gain	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Top Glazing	0	n/a	0	1	n/a	n/a	1	n/a	1	3
Clerestory Glazing	0	n/a	0	0	n/a	n/a	0	n/a	1	1
Vertical Glazing	1	n/a	1	1	n/a	n/a	1	n/a	1	5
North Facing	1	n/a	0	1	n/a	n/a	1	n/a	1	4
East Facing	1	n/a	0	0	n/a	n/a	1	n/a	1	3
South Facing	0	n/a	1	0	n/a	n/a	1	n/a	1	3
West Facing	1	n/a	0	0	n/a	n/a	1	n/a	0	2
Mirror Assist/ Heliostats	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Passive Air Handling Strategy	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Pre-Conditioning Atrium	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Exhaust/Cooling Atrium	0	n/a	0	0	n/a	n/a	1	n/a	0	1
Use of Solar Chimney	0	n/a	0	0	n/a	n/a	0	n/a	0	0
Self Proclaimed Green	0	0	0	1	0	0	1	0	0	2
LEED Certified	0	0	0	0	0	0	0	0	0	0

Catalogue #	B.007	B.018	B.037	B.038	B.043	B.056	B.059	B.060	B.062	B.068	B.077	B.078	B.089	B.098	B.103	B.104	
Building Name	University Plaza Building	Centre for Construction Trades and Technology T' Building	Gordon Hall/ Gordon Annex	Haynes Hall	Faculty of Business Building	DNA Building	Biodiversity Institute of Ontario (BIO)	MacKinnon Extension	Science Complex Phase 2A - 2B	Roger-Guindon Hall	Communication, Culture & Information Technology Building (CCIT)	The Leslie L. Dan Pharmacy Building	Clinical Skills Building	St. Jerome's Campus, Kitchener	Accolade East	Accolade West	2006 Totals
Institution	Brock University	Fanshawe College	Queen's University	Queen's University	Ryerson University	Trent University	University of Guelph	University of Guelph	University of Guelph	University of Ottawa	University of Toronto - Miss	University of Toronto	University of Western Ontario	Wilfred Laurier University	York University	York University	16 Buildings
Year of Completion	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006	
Square Footage	90,811 sqft	104,498 sqft	62,300 sqft	3,500 sqft	210,000 sqft	57,900 sqft	15,000 sqft	33,400 sqft	230,000 sqft	98,000 sqft	112,819 sqft	167,000 sqft	24,000 sqft	39,182 sqft	280,550 sqft	77,155 sqft	
Number of Levels	6.0 levels	3.0 levels	4.0 levels	3.0 levels	8.0 levels	2.0 levels	2.0 levels	4.0 levels	4.0 levels	4.0 levels	4.5 levels	12.0 levels	3.0 levels	4.0 levels	4.0 levels	4.0 levels	
Atrium Space Present	1	1	0	0	1	1	1	0	1	0	1	1	0	0	0	1	9
Atrium Height (levels)	3.5 levels	2.0 levels	n/a	n/a	6.0 levels	2.0 levels	2.0 levels	n/a	4.0 levels	n/a	4.5 levels	12.0 levels	n/a	n/a	n/a	3.0 levels	
Full Building Height	0	0	n/a	n/a	0	1	1	n/a	1	n/a	1	1	n/a	n/a	n/a	1	6
Category of Atrium Form	3 Sided	Partial 1 Sided	n/a	n/a	Partial 2 Sided	Partial 1 Sided	Linear	n/a	Closed	n/a	Multi-Lateral 1S + 3S	Multi- Lateral Closed + 3S	n/a	n/a	n/a	Partial Closed	
Located Centrally	0	0	n/a	n/a	0	0	1	n/a	1	n/a	1	1	n/a	n/a	n/a	1	5
Located on Perimeter	1	1	n/a	n/a	1	1	0	n/a	0	n/a	1	1	n/a	n/a	n/a	0	6
Closed Atrium	0	0	n/a	n/a	0	0	0	n/a	1	n/a	0	0	n/a	n/a	n/a	0	1
1 Sided Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
2 Sided Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
3 Sided Atrium	1	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	1
Linear Atrium	0	0	n/a	n/a	0	0	1	n/a	0	n/a	0	0	n/a	n/a	n/a	0	1
Partial	0	1	n/a	n/a	1	1	0	n/a	0	n/a	0	0	n/a	n/a	n/a	1	4
Bridging Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Podium Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Multi-Lateral Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	1	1	n/a	n/a	n/a	0	2
Multi-Vertical Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Integrated Horizontal Circ	1	1	n/a	n/a	0	0	1	n/a	0	n/a	1	0	n/a	n/a	n/a	1	5
Includes Vertical Circ	1	1	n/a	n/a	1	0	0	n/a	1	n/a	1	1	n/a	n/a	n/a	0	6
Building Hub	1	0	n/a	n/a	0	0	1	n/a	1	n/a	1	1	n/a	n/a	n/a	1	6
Connection Adaptation	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Renovation Adaptation	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Historical Preservation	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Diverse Space	1	0	n/a	n/a	0	1	0	n/a	1	n/a	1	1	n/a	n/a	n/a	1	6
Future Reuse	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Daylighting	1	1	n/a	n/a	1	1	1	n/a	1	n/a	1	1	n/a	n/a	n/a	1	9
Controlled Solar Gain	1	0	n/a	n/a	0	0	0	n/a	0	n/a	0	1	n/a	n/a	n/a	0	2
Top Glazing	0	0	n/a	n/a	0	0	0	n/a	1	n/a	1	1	n/a	n/a	n/a	0	3
Clerestory Glazing	0	0	n/a	n/a	0	0	0	n/a	1	n/a	1	0	n/a	n/a	n/a	1	3
Vertical Glazing	1	1	n/a	n/a	1	1	1	n/a	0	n/a	1	1	n/a	n/a	n/a	0	7
North Facing	1	0	n/a	n/a	1	0	1	n/a	0	n/a	0	1	n/a	n/a	n/a	1	5
East Facing	1	0	n/a	n/a	1	1	0	n/a	1	n/a	1	1	n/a	n/a	n/a	0	6
South Facing	0	1	n/a	n/a	0	0	1	n/a	0	n/a	1	1	n/a	n/a	n/a	0	4
West Facing	1	0	n/a	n/a	0	0	0	n/a	0	n/a	1	0	n/a	n/a	n/a	1	3
Mirror Assist/ Heliostats	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Passive Air Handling Strategy	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	1	n/a	n/a	n/a	0	1
Pre-Conditioning Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Exhaust/Cooling Atrium	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	1	n/a	n/a	n/a	0	1
Use of Solar Chimney	0	0	n/a	n/a	0	0	0	n/a	0	n/a	0	0	n/a	n/a	n/a	0	0
Self Proclaimed Green	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
LEED Certified	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Catalogue #																
Building Name	2000 Totals		2001 Totals		2002 Totals		2003 Totals		2004 Totals		2005 Totals		2006 Totals		Survey Totals	Building Name
Institution	5 Buildings		6 Buildings		19 Buildings		22 Buildings		27 Buildings		9 Buildings		16 Buildings		104 Buildings	Institution
Year of Completion																Year of Completion
Square Footage																Square Footage
Number of Levels																Number of Levels
Atrium Space Present	4		4		10		15		16		5		9		63	Atrium Space Present
Atrium Height (levels)																Atrium Height (levels)
Full Building Height	3		2		8		11		12		2		6		44	Full Building Height
Category of Atrium Form																Category of Atrium Form
Located Centrally	2		2		4		9		13		3		5		38	Located Centrally
Located on Perimeter	3		2		6		7		4		3		6		31	Located on Perimeter
Closed Atrium	0		0		1		2		2		0		1		6	Closed Atrium
1 Sided Atrium	2		1		3		0		0		0		0		6	1 Sided Atrium
2 Sided Atrium	0		0		1		0		0		0		0		1	2 Sided Atrium
3 Sided Atrium	0		0		0		0		0		0		1		1	3 Sided Atrium
Linear Atrium	0		0		1		1		4		2		1		9	Linear Atrium
Partial	1		2		3		8		7		2		4		27	Partial
Bridging Atrium	0		0		1		0		0		0		0		1	Bridging Atrium
Podium Atrium	0		0		0		0		0		0		0		0	Podium Atrium
Multi-Lateral Atrium	1		1		0		4		3		0		2		11	Multi-Lateral Atrium
Multi-Vertical Atrium	0		0		0		0		0		1		0		1	Multi-Vertical Atrium
Integrated Horizontal Circ	2		3		6		10		7		2		5		35	Integrated Horizontal Circ
Includes Vertical Circ	3		2		8		7		10		4		6		40	Includes Vertical Circ
Building Hub	2		2		9		10		11		3		6		43	Building Hub
Connection Adaptation																Connection Adaptation
Renovation Adaptation	0		0		0		0		4		0		0		4	Renovation Adaptation
Historical Preservation	0		0		1		0		0		1		0		2	Historical Preservation
Diverse Space	2		2		6		10		10		4		6		40	Diverse Space
Future Reuse	0		3		0		3		3		1		0		10	Future Reuse
Daylighting	4		4		10		14		15		5		9		61	Daylighting
Controlled Solar Gain	0		1		2		4		6		1		2		16	Controlled Solar Gain
Top Glazing	2		4		4		6		11		3		3		33	Top Glazing
Clerestory Glazing	0		2		1		9		4		1		3		20	Clerestory Glazing
Vertical Glazing	4		3		8		10		9		5		7		46	Vertical Glazing
North Facing	2		1		5		8		5		4		5		30	North Facing
East Facing	1		0		3		11		5		3		6		29	East Facing
South Facing	2		3		2		6		3		3		4		23	South Facing
West Facing	1		0		5		8		6		2		3		25	West Facing
Mirror Assist/ Heliostats	0		0		0		0		0		0		0		0	Mirror Assist/ Heliostats
Passive Air Handling Strategy	0		1		2		4		3		1		1		12	Passive Air Handling Strategy
Pre-Conditioning Atrium	0		0		1		0		0		0		0		1	Pre-Conditioning Atrium
Exhaust/Cooling Atrium	0		1		1		4		3		1		1		11	Exhaust/Cooling Atrium
Use of Solar Chimney	0		1		0		2		0		0		0		3	Use of Solar Chimney
Self Proclaimed Green	0		1		3		6		4		2		2		18	Self Proclaimed Green
LEED Certified	0		0		0		0		0		0		1		1	LEED Certified

## Endnotes

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- <sup>1</sup> Building Ontario's Future A Superbuild Government of Ontario: Ministry of Finance, "Building Ontario's Future A Superbuild Progress Report," <http://www.fin.gov.on.ca/english/budget/bud01/papere.html> (24 October 2006).
- <sup>2</sup> It should also be noted that this study group does not include all post secondary institutions in Ontario: 14 institutions in the province of Ontario were excluded either because there was not enough available information to properly address the institution's recent construction or the institution was located outside of what was considered Southern Ontario (ie Sudbury or Thunder Bay).

## Survey Notes

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<sup>S1</sup> **Ontario Universities NOT Included**

Dominican University College  
Lakehead University  
Laurentian University  
Nipissing University  
Royal Military College

<sup>S2</sup> **Ontario Colleges NOT Included**

Cambrian College of Applied Arts and Technology  
Canadore College of Applied Arts and Technology  
Collège Boréal  
Confederation College of Applied Arts and Technology  
La Cité Collégiale  
Lambton College of Applied Arts and Technology  
Loyalist College of Applied Arts and Technology  
Northern College of Applied Arts and Technology  
Sault College of Applied Arts and Technology

- <sup>S3</sup> The information gathered for the survey of new academic buildings was compiled from a multitude of sources in conjunction with site visits to all buildings by the author. For a complete list of sources used to gather building information and critique the building attributes for comparison, can be found in the Bibliography under the sub-section Resources for Survey Information.



## **Part 3 :: Results, Patterns + Trends**

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## Overall Survey Results

### 3.1

The majority of the Academic Building Survey was compiled in the fall of 2006, with minor follow ups completed in the winter of 2007. The survey includes all academic buildings within thirty institutions across Southern Ontario.<sup>1</sup> Choosing to focus in on solely academic building types, the survey did not include library buildings, student centres or student residences. The survey produced a total of 104 buildings built within a seven year time frame, beginning in 2000 and culminating at the end of 2006. As mentioned, this time period encompasses both the Provincial Government's allotment of their Superbuild funding and the full realization of completed projects. As a result of the established funding, the annual number of completed projects begins low in 2000 and reaches its peak in 2004, to then slow up in 2005 and 2006 where building funding returned to more normal patterns. Looking at graph 3G.6, (section 3.2) this pattern is illustrated in the line denoting total buildings. Likewise a breakdown can be seen per annum in the subsequent breakdown of annual pie graphs for 3G.5 (in combination with atrium inclusion).

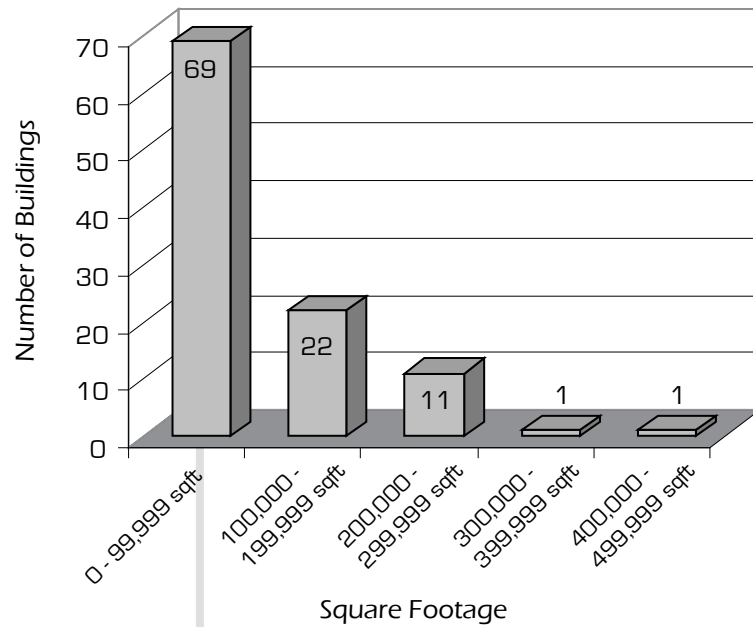
With no restriction on building size or height, the range seen of both characteristics varied. The buildings' sizes in the survey range from as small as 3,500 square feet up to 400,000 square feet. Of the 104 academic buildings surveyed, it was found that a majority of buildings which were up to 199,999 square feet, representing approximately 88% of the buildings surveyed (illustrated in graph 3G.1). This best represents the general scale of most academic projects, as anything larger than 200,000 square feet is rare for an academic building. The largest portion of buildings in the 0 – 199,999 square feet are those under 100,000 square feet. A subsequent breakdown of the 0



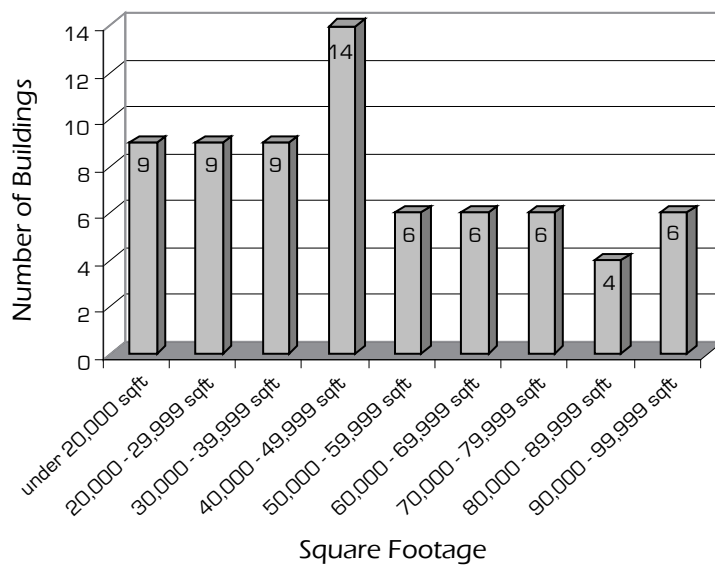
fig. 3.01 - Sheridan College's SCAET is just one of 104 identified new academic projects built since 2000 at Universities and Colleges across Southern Ontario

fig. 3.02 - (opposite) Collage of atrium spaces seen within the academic buildings visited as part of the completed survey

3G.1 - Complete Survey



3G.2 - Breakdown 0 - 99,000 sqft



– 99,999 square feet building category, (graph 3G.2) reveals a fairly proportional distribution among each 10, 000 square foot breakdown.

The range in building height of the surveyed buildings similarly varies, from as low as a single storey to as high as 12 storeys. A numerical break down of each building height occurrence can be seen in graph 3G.3. The majority of buildings are 5 storeys or less, (93 buildings or 89%) an indication that anything greater than 5 storeys becomes rather uncharacteristic of an academic building typology. The largest collection of buildings in the survey is found to be within 3 or 4 storeys, each representing 28 percent and cumulatively over half of the buildings at 57 percent. Only 7 buildings were found to exceed 6 storeys, which upon further examination is most likely related to their location within the city of Toronto where higher densities are maintained/required.

The survey was not solely limited to new buildings, so as to address some of the atrium’s conservational characteristics rooted in building additions and renovations. Therefore the survey endeavored to be thorough in identifying all construction projects completed on university and college campuses across southern Ontario in order to assess the atrium’s role in all recent buildings. It should be noted that 18 of the 104 buildings (17 percent) were additions to existing buildings and 11 of the 104 buildings (11 percent) were renovations to existing buildings that were previously not post secondary academic buildings (see cumulative graph 3G.4, accompanied with a list of addition and renovation buildings)

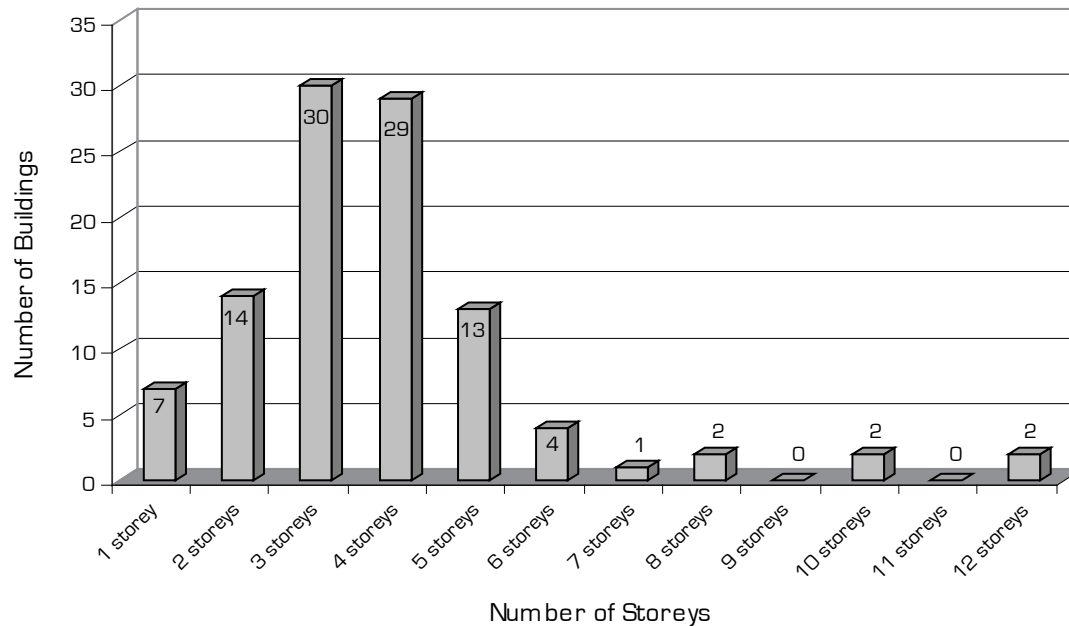
Upon review of the buildings surveyed, it was found that 18 buildings consider themselves to be designed ‘green’ and maintain some variation of sustainable characteristics. This represents approximately a sixth (or 17 percent) of the buildings in the survey, and is a highly inflated representation compared to the overall general construction of new buildings. Even in Canada’s hot spot of eco-enthusiasts and ‘green’ building in the Greater Vancouver Regional District, a study in 2004 has shown that only 1 percent of all construction in that area was deemed ‘green’ design<sup>2</sup>. This fact suggests that the academic buildings are ahead in the ‘green’ building agenda allowing themselves to be grounds of experimentation and leadership for future and other ‘green’ buildings. Similarly, this can be seen as a direct relationship to the institutions which they house, whom are known for experimentation, enlightenment and forward thinking. Amongst these ‘green’ buildings found in the survey, only two buildings have procured ‘green’ certification, one through LEED (Leadership in Energy and Environmental Design)

**Overall Survey Synopsis**

- 104 Buildings Total
- 75 New Buildings ( 72 % )
- 18 Additions ( 17 % )
- 11 Renovations ( 11 % )
- Characteristically Buildings are between 0 – 199,999 SQFT ( 88 % )
- 69 are 0 – 99,999 SQFT ( 66 % )
- Characteristically Buildings are between 1 and 5 storeys ( 89 % )
- 30 are 3 storeys ( 29 % )
- 29 are 4 storey ( 28 % )
- 18 Buildings consider themselves ‘green’ ( 17 % )
- 1 Building is LEED certified (silver)
- 1 Building is Green Globe certified (4 leaves)

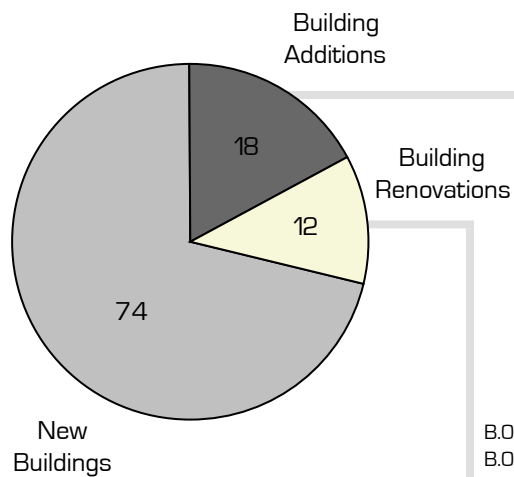
Graph 3G.3

## Building Height



Graph 3G.4

## Building Project Type



B.004 • Scotia Bank Hall  
 B.008 • The Minto Center for Engineering Studies Addition  
 B.013 • Nesbitt Biology Building Addition  
 B.017 • 'F' Building West Addition  
 B.025 • AIC Wing - School of Business Expansion  
 B.026 • Arthur Bourns Building Expansion  
 B.027 • Information Technology Building Extension  
 B.034 • Goodes Hall  
 B.039 • Horsfall Eaton Centre for Studies in Community Health  
 B.057 • Access to Opportunities Program Building (ATOP)  
 B.060 • MacKinnon Extension  
 B.068 • Roger-Guindon Hall  
 B.069 • Davenport Chemical Research Building  
 B.071 • Centre for Applied Bioscience and Biotechnology  
 B.072 • Sidney Smith Infill Project  
 B.083 • Lawrence National Centre for Policy and Management  
 B.085 • Spencer Engineering Building Addition  
 B.093 • Arts C Wing Addition

B.012 • H M Tory Building  
 B.022 • Computer Technology Centre - Building 'F'  
 B.028 • James Stewart Centre for Mathematics  
 B.032 • Sharp Centre for Design/ 100 McCaul St  
 B.037 • Gordon Hall / Gordon Annex  
 B.038 • Haynes Hall  
 B.048 • Markham Campus  
 B.074 • School of Continuing Studies  
 B.081 • School of Architecture  
 B.092 • St. Michael's Campus  
 B.096 • Odeon Brantford Campus  
 B.098 • St. Jerome's Campus

and the other through Green Globes; these are University Plaza Building at Brock University and Beamish Munro Hall/Integrated Learning Centre at Queen's University respectively.

Relevant to the overall intention of this thesis study of conservationism and sustainability, the collection of buildings is highlighted in table 3.1 briefly noting their 'green' qualities. As further examination of the atrium element is conducted throughout this section, the collection of self proclaimed 'green' buildings will be revisited to compare the atrium's role in decided green buildings as compared to in non-green buildings. This examination of the atrium and its characteristics begins in the following section.

Table 3.1

## Self Proclaimed 'Green' Buildings

### York Computer Science Building

York University

B.099



2001

- By utilizing the multiple atrium spaces, extensive natural illumination and ventilation are provided, reducing the size of mechanical equipment and in turn reducing energy
- Other strategies include material recycling, such as the use of fly ash; storm water retention and recycling; use of low flow faucets/toilets; exposed concrete slabs for thermal mass

### National Wildlife Research Centre at the Nesbitt Building

Carleton University

B.011



2002

- Designed as an environmentally progressive research laboratory to address the environmentally sensitive site
- Storm water is managed through a sustainable dispersion wetland of indigenous vegetation
- The building offers the highest level of energy efficiency and indoor environmental quality

### School of Information Technology and Engineering (SITE)

University of Ottawa

B.065



2002

- Integrated system of thermal storage and air delivery within pre-cast planks which radiate or absorb energy eliminating convective heating/cooling; utilizing thermal mass
- The atrium captures solar radiation to pre-condition fresh air
- Increased insulation and triple glazing offer efficient building envelope, assisting with energy efficiency of 14.5kW/day/year

### Bahen Centre for Information Technology

University of Toronto

B.070



2002

- Maximized glazing for natural daylighting with sunshading to reduce the need for utilities without increasing heat gain
- Natural ventilation by using the atrium as a thermal chimney
- Other strategies include storm water retention and recycling; use of low flow faucets/toilets; exposed concrete slabs for thermal mass

### HP Science and Technology Centre

Centennial College

B.014



2003

- Maximized glazing for natural daylighting including overhangs, louvres and fritted glass to reduce artificial lighting without increasing heat gain; Exposed concrete to utilize thermal mass
- Natural ventilation by using the atrium as a thermal chimney with windows and underfloor plenums for air distribution
- Storm water retention and soil remediation to revitalize site



## Technology Wing Southerland Campus

### Sir Sandford Fleming College

- The central atrium maximizes daylighting using the skylight roof and light shelves to distribute and control the light
- Natural ventilation is accomplished with three thermal chimneys using air stratification to move air within the building
- Increased insulation along with mechanical systems using heat exchangers and economizers reduce energy consumption



B.052

## Chemical Sciences Building

### Trent University

- Design targeted issues of sustainable development by using living roofs to reduce storm water run off and reduce heat islanding as well as integrated heat recovery systems
- New labs incorporate a variable air volume system for fume hood exhaust to minimize energy consumption



B.054

## Science Building

### University of Ontario Institute of Technology

- Atrium facilitates both infusion of natural daylight and acts as a return plenum for collecting and refreshing spent air
- Use of closed loop borehole thermal energy storage
- Use of vegetation to facilitate air biofilter, green roofs and integrated storm water management wetlands
- Triple glazing and increased insulation for fortified envelope



B.063

## Centre for Environmental and Information Technology

### University of Waterloo

- Design targeted issues of sustainable development by using grey water/black water systems to conserve water, storm water ponding and filtration systems, as well as heat reclaim from laboratory exhaust systems
- New labs incorporate a variable air volume system for fume hood exhaust to minimize energy consumption



B.080

## TEL Building

### York University

- Energy efficient measures were implemented to support sustainability and to realize a 25% reduction in energy consumption
- Three distinct atria bring copious amounts of natural light throughout the building, as well as offering natural air movement by exhausting stratified hot air



B.101

Table 3.1

## Self Proclaimed 'Green' Buildings cont'd

B.023



### University of Guelph-Humber Building

Humber College

- Four storey sky lit atrium providing daylighting to protruding balconies used as informal workspaces
- Four storey living biofilter within the atrium, which uses displacement ventilation to condition and optimize building air quality and the indoor environment

B.036



### Beamish Munro Hall/ Integrated Learning Centre

Queen's University

- Received Green Globes 4 Leaf Certification
- Saw toothed section and light scoops allow natural light in
- Biofilter wall which filters incoming air into the building
- Strategic design to allow displacement ventilation
- Energy saving systems such as heat exchangers, high efficiency motors and low flow faucets and toilets to reduce utilities

B.053



### School of Environmental and Natural Resource Studies

Sir Sandford Fleming College

- Windows and overhangs maximize natural daylighting reducing the need for utilities without increasing heat gain
- Natural ventilation is accomplished with strategical building design
- The use of underground heat pumps to maintain the building
- Included space for research into alternative energy sources

B.064



### Business and IT Building

University of Ontario Institute of Technology

- Atrium facilitates both infusion of natural daylight and acts as a return plenum for collecting and refreshing spent air
- Use of closed loop borehole thermal energy storage
- Use of vegetation to facilitate air biofilter, green roofs and integrated storm water management wetlands
- Triple glazing and increased insulation for fortified envelope

### **Centre for Design and Manufacturing Technologies**

**Sheridan College**

- Integrated system of thermal storage and air delivery within pre-cast planks which radiate or absorb energy eliminating convective heating/cooling; ductwork is reduced
- Significant energy savings and enhanced user comfort utilizing thermal mass; 100% fresh air used



B.057

### **The Terrance Donnelly Centre for Cellular and Biomolecular Research**

**University of Toronto**

- Each facade is unique to address its orientation and maximize daylighting while minimizing radiant thermal loads
- Double skin south facade is integrated to facilitate sunshading, natural ventilation and thermal insulation
- Automatic operable windows used to help ventilate spaces
- Roof cisterns collect rain water to irrigate interior gardens

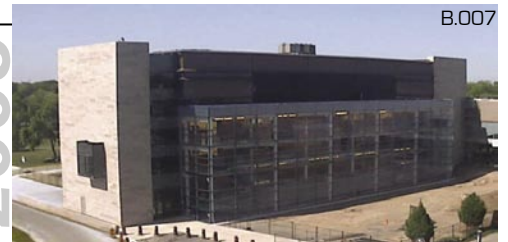


B.076

### **University Plaza Building**

**Brock University**

- Designed in accordance with LEED to achieve a silver rating
- Incorporates innovative energy efficient approach to heating and cooling utilizing the core of the concrete slabs
- Energy is radiated or absorbed by the concrete eliminating convective heating/cooling which achieves a greater energy efficiency



B.007

### **The Leslie L Dan Pharmacy Building**

**University of Toronto**

- Narrow atrium runs up through the building to bring natural light into the laboratory support spaces and provides air exhausting through air stratification
- The building offers the highest level of energy efficiency and indoor environmental quality



B.078

## 3.2

## Atrium Inclusion Results + Analysis



fig. 3.03 - The central stepped atrium at Beamish Munro Hall at Queen's University - one of sixty three recognized atria in the survey group of new academic buildings.

Upon review of the survey group for atrium inclusion, 63 cases were identified. These instances range in scale and complexity and each exemplifies atrium characteristics to some varying degree. (See graphs 3G.5 - 7 for overall and annual breakdowns of atrium inclusion) As a total, the inclusion of atria occurs in approximately 61 percent or in nearly two-thirds of the recently constructed academic buildings at post-secondary institutions in Southern Ontario. The atrium's strong presence within recent academic building design echoes trends of prevalent atrium inclusion in a broad range of building types. With no similar study of atrium inclusion to be found in this or any other area of architectural construction, it is uncertain whether this is a normal or high rate of inclusion. Nevertheless, it is an indisputable acknowledgement of our continued attraction to the atrium space, and more specifically the proliferation of the atrium. The overwhelming presence of atria in academic buildings goes beyond the typical perception of inclusion in office, commercial and hotel spaces.

Narrowing in on the atria within the survey, trends of inclusion can be perceived. Looking at the graphs 3G.8 - 10, a comparison is shown between atria inclusion and building size, height and project type.

A direct correlation between building size and atrium inclusion can be made. With the increase in building size, a similar increase in atrium inclusion occurs. This is shown by the dashed line of average inclusion in graph 3G.8. This relation is to be expected as the larger the building, the more useful an atrium space becomes as atria can break up large floor plates of bigger buildings. The division of a floor plate can be useful for allowing more daylighting in, to make better use of deep areas within a building and/or can break up and organize the building into different areas or wings. As for the trends of atria against building height, there appears to be no correlation. As seen in graph 3G.10, other than a low inclusion for single storey buildings (which is to be expected by their typology), the rates are scattered between 55 percent and 71 percent, with no increase or decrease with similar increase or decrease in building height. Within the building project types, five of the eighteen building additions have included atria as part of their design, resulting in a lower than survey inclusion rate of 28 percent. Similarly, five of the twelve building renovations (42 percent) included atria in the renovation of their buildings, also resulting in a lower than survey trend. Whereas the atrium inclusion rate

within completely new buildings increased once removing both additions and renovations (up to 72 percent).

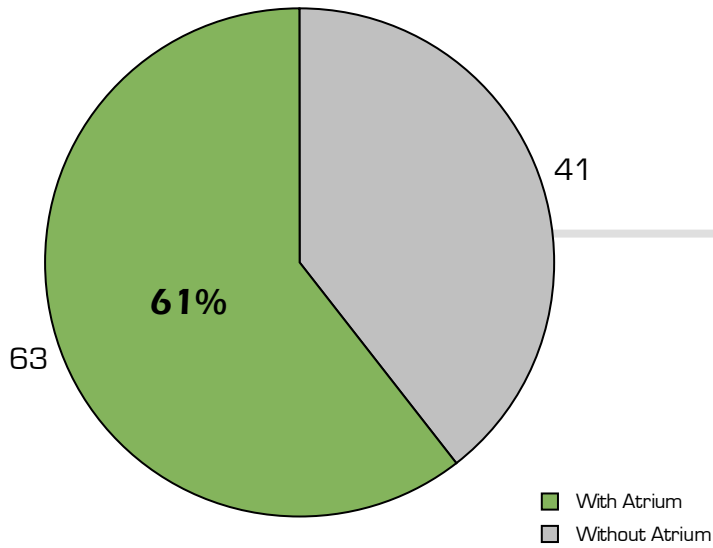
Grouping the atria using the generic atrium types, compiled from the works of Dixon and Bedner (as outlined in section 1.4), the frequency of each atrium type is shown. Seen in graph section 3G.11 is the atrium type occurrence along with the breakdown of each sub-type occurrence. It was found that the atria documented in the survey group most commonly occur in the partial atrium category (43 percent), followed closely by simple atrium (36 percent) while the remaining portion fall into the complex atrium category (21 percent). The large partial atrium count shows the tendency of many atria to interact only with a portion of their overall building. Nevertheless the combined total of simple and complex atria, which are more holistically integrated atria designs, still maintain the majority. The lower numbers for the complex atrium type alone is to be expected due to complex atria being better suited for commercial functions such as offices and shopping centres. Further breakdown totals of sub-types for each main type can also be seen in graphs 3G.12 - 14.

In addition, the survey documented the location where atria were found, either centrally located surrounded by building or located on the periphery of the building. The survey found that the placement was closely distributed between the two, with centrally located atria favoured (see graphs 3G.15 + 16). Furthermore, by looking at the location of the atrium against atrium type, using graphs 3G.18 – 20, a coherent pattern is seen as a larger portion of simple atrium are located centrally within buildings, while the opposite occurs with partial atria, where a larger portion are located on the periphery of the building. The complex atria type maintains all instances of buildings with atria in both locations due to the multi-lateral and multi-vertical sub-types belonging to the complex atrium category.

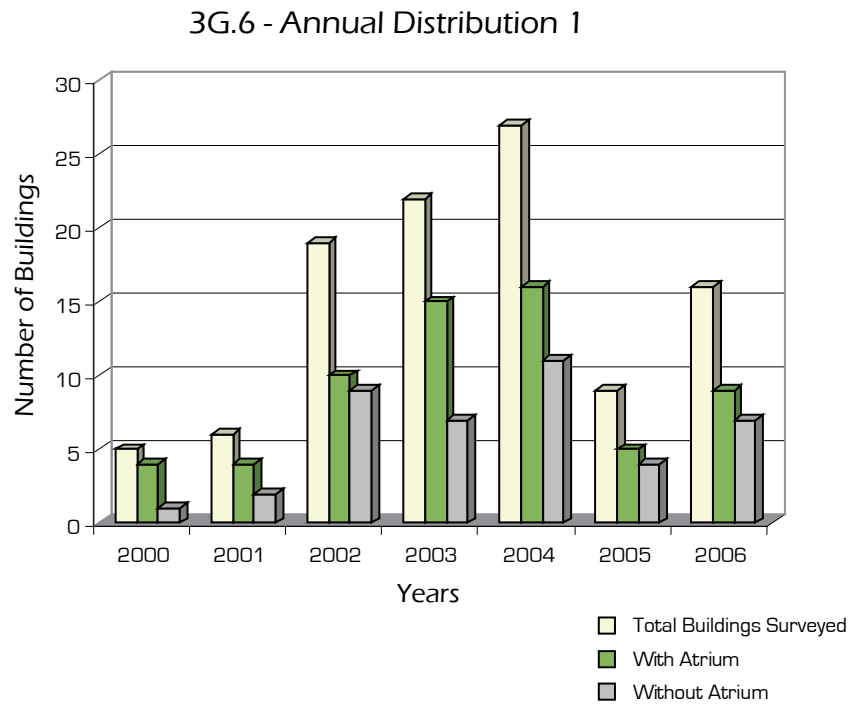
Atrium Inclusion Synopsis	
63 Buildings with Atrium [ 61 % ]	
27 Partial Atria [ 43 % ]	
23 Simple Atria [ 36 % ]	
13 Complex Atria [ 21 % ]	
32 Centrally Located Atria [ 51 % ]	
25 Peripherally Located Atria [ 40 % ]	
6 With Atria at Both [ 9 % ]	
68 % Atria act as Hubs	
63 % Atria with Vertical Circulation	
49 % Atria with Horizontal Circulation	
14 % Atria with Nothing	
17/18 'Green' Buildings with Atria [ 94 % ]	

Graph 3G.5 - 7

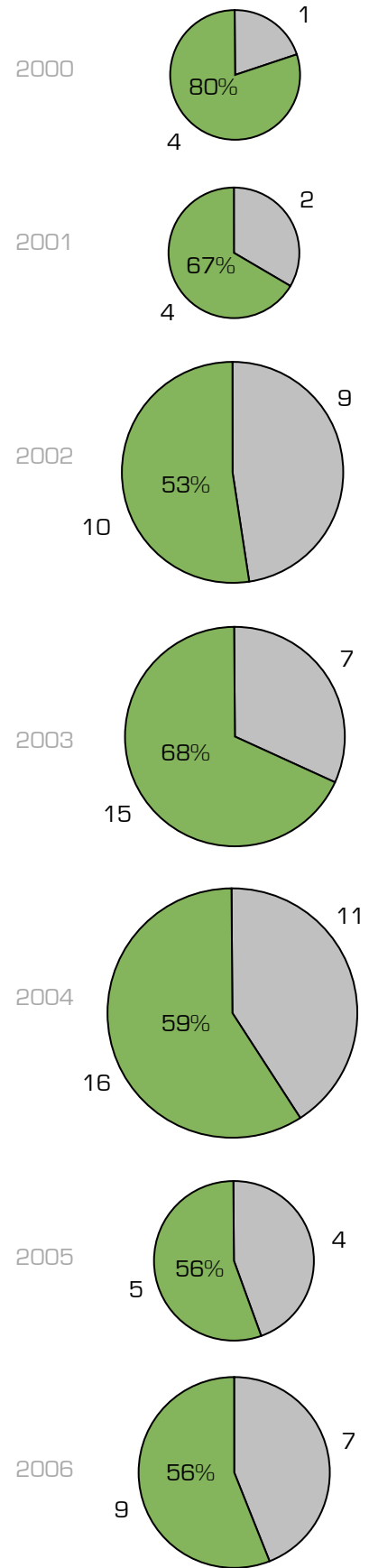
## Atrium Inclusion



3G.5 - Survey Totals



3G.6 - Annual Distribution 1



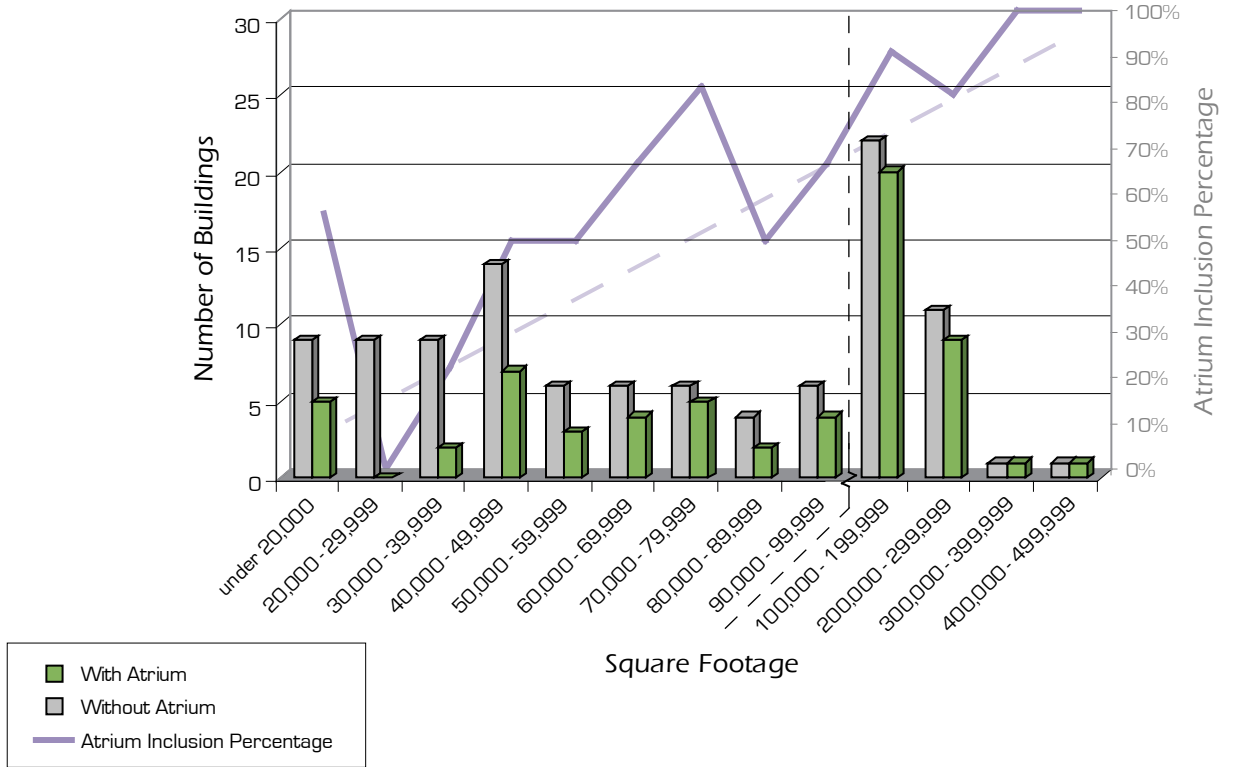
3G.7 - Annual Distribution 2



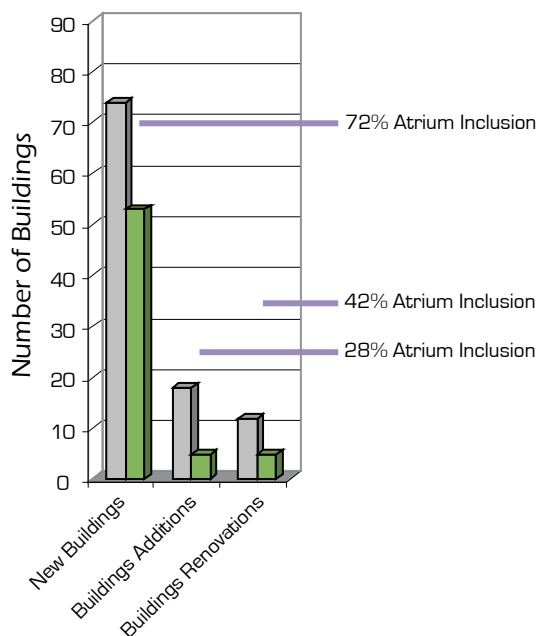
## Atrium Inclusion Comparison

Graph 3G.8 - 10

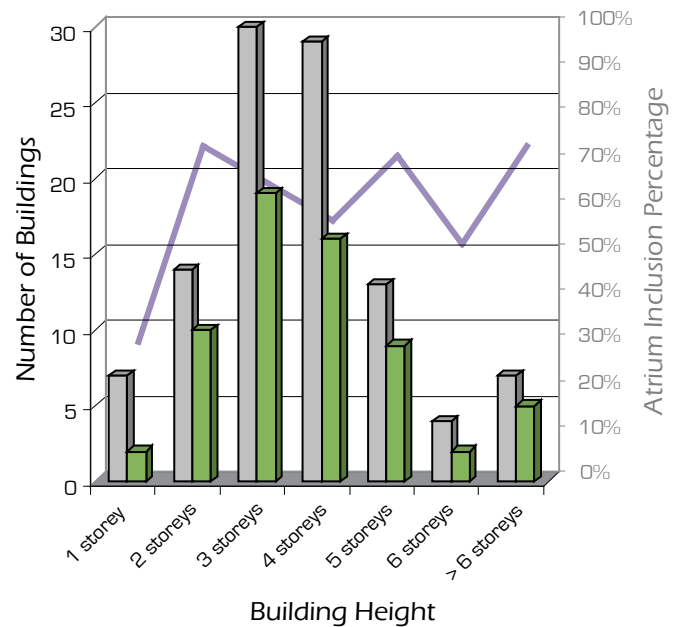
3G.8 - Atrium Inclusion vs Building Size



3G.9 - Atrium Inclusion vs Project Type

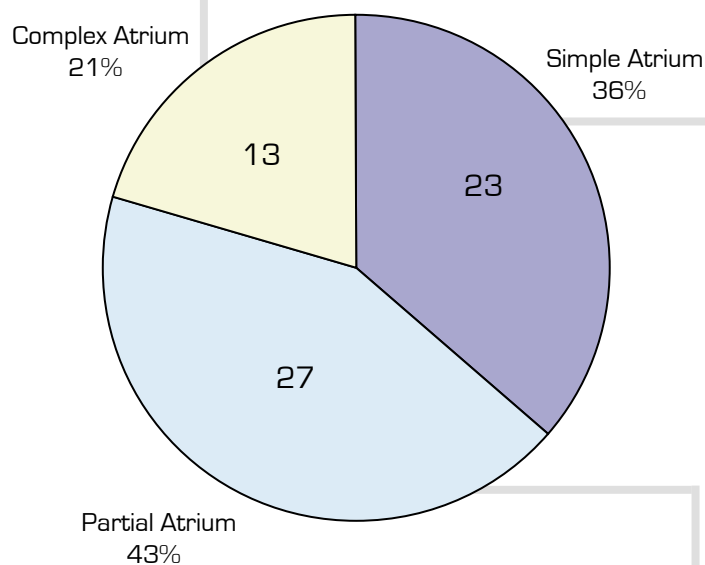


3G.10 - Atrium Inclusion vs Building Height

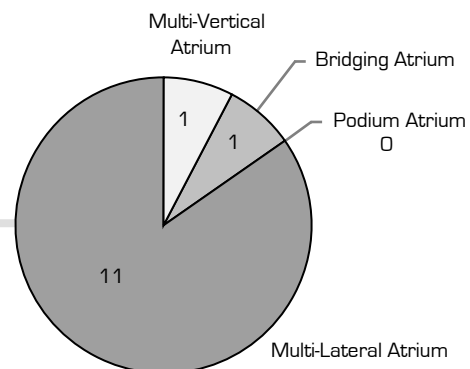




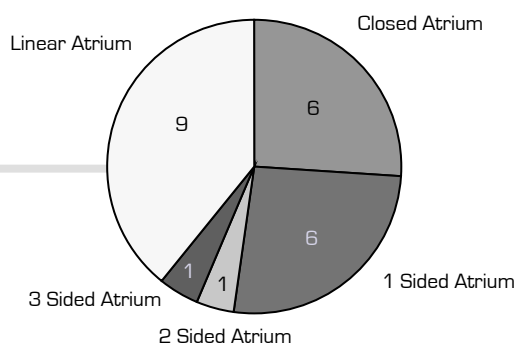
## Atrium Type



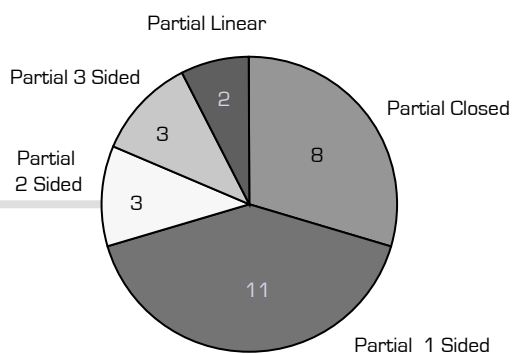
3G.11 - Atrium Type



3G.12 - Breakdown of Complex Atria

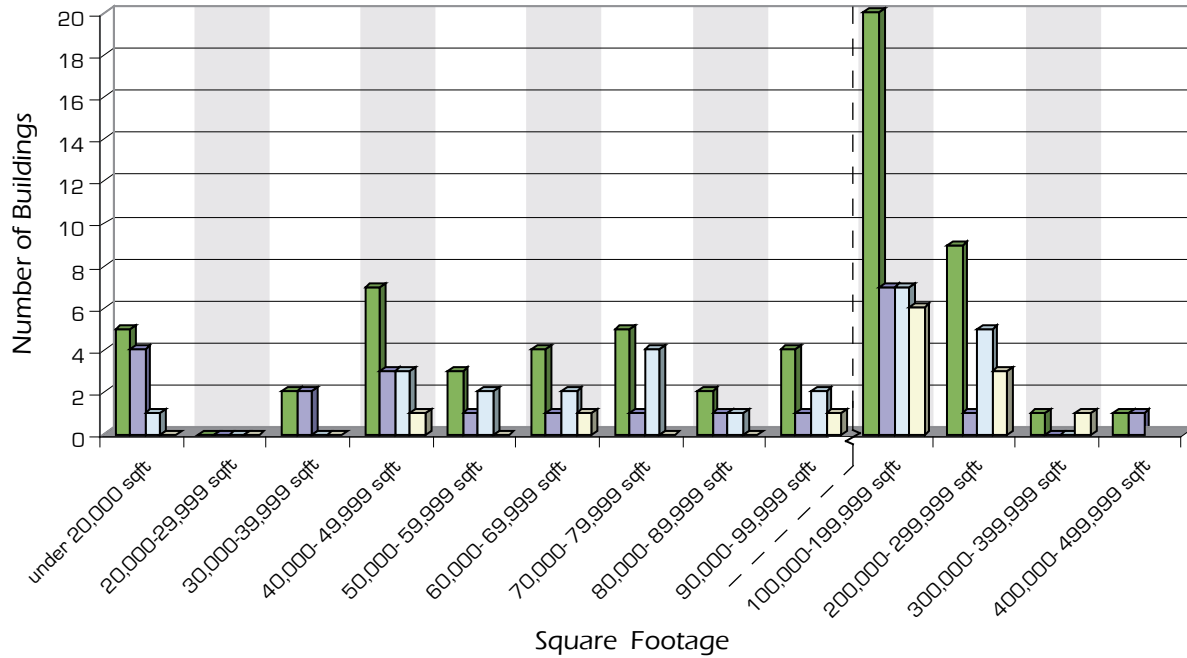


3G.13 - Breakdown of Simple Atria



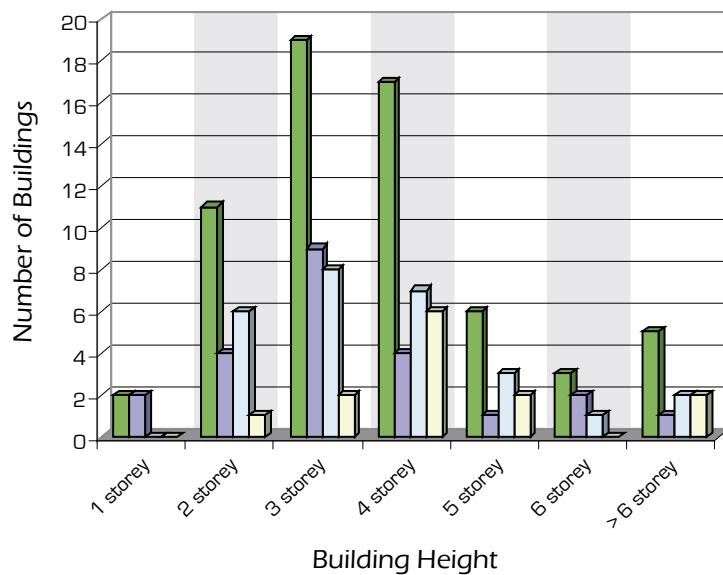
3G.14 - Breakdown of Partial Atria

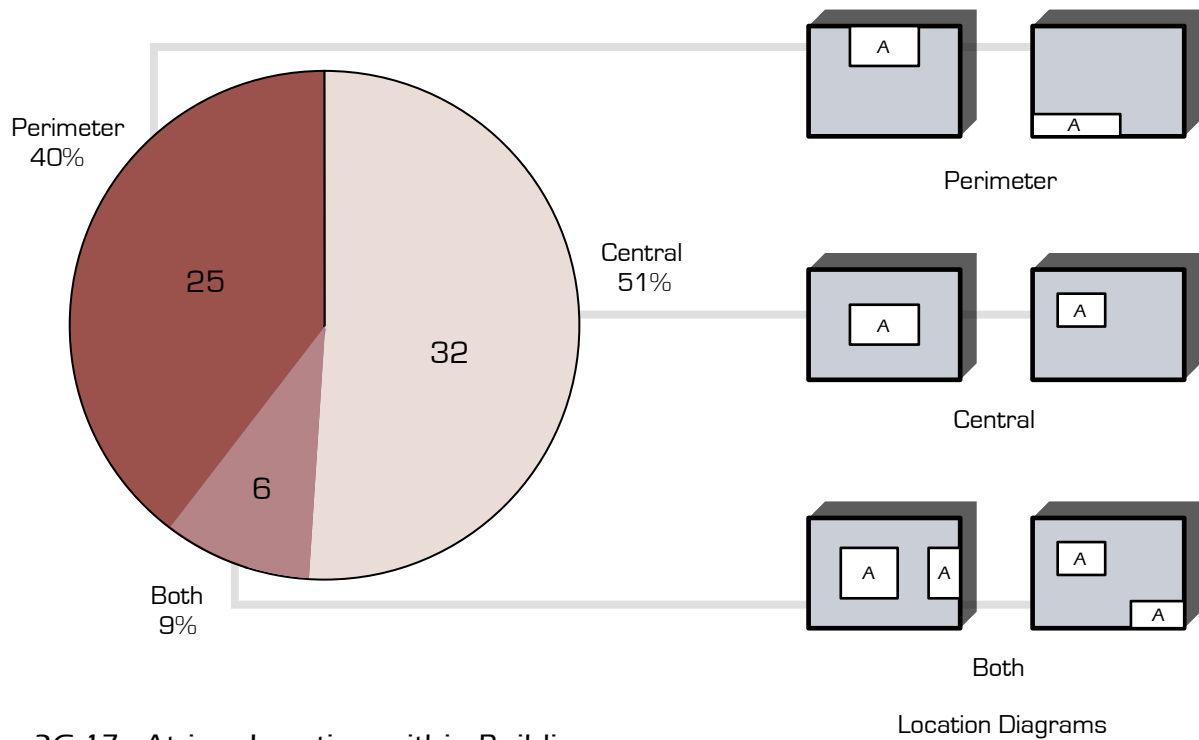
3G.15 - Atrium Type vs Building Size



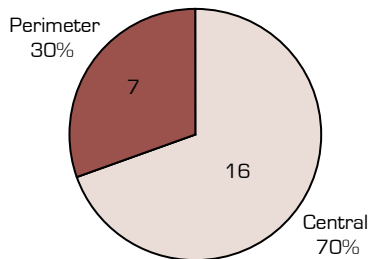
- Atrium Total
- Simple Atrium Type Totals
- Partial Atrium Type Totals
- Complex Atrium Type Totals

3G.16 - Atrium Type vs Building Height

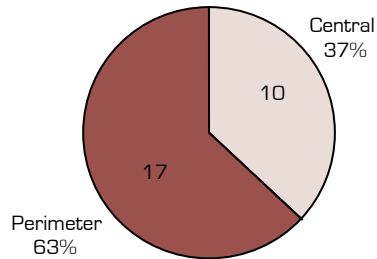




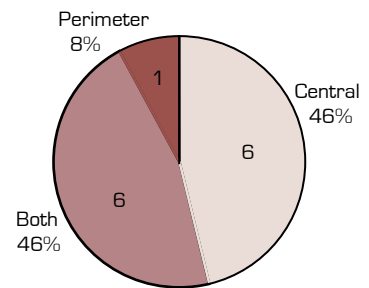
3G.17 - Atrium Location within Building



3G.18 - Simple Atrium Location

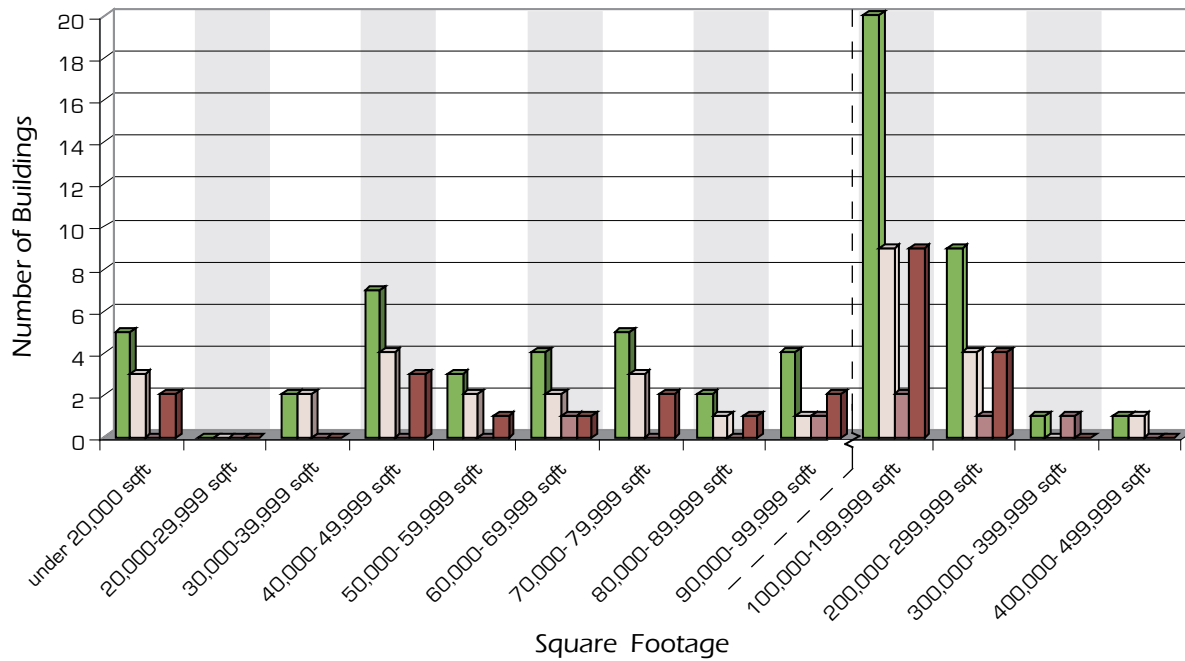


3G.19 - Partial Atrium Location



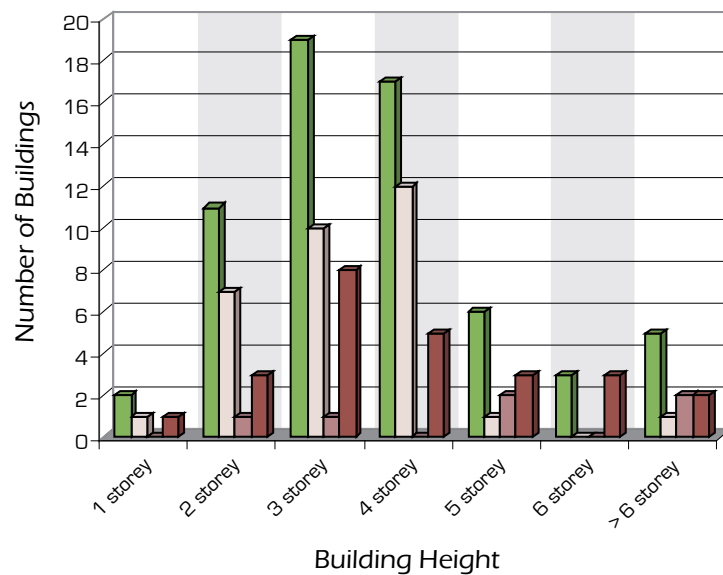
3G.20 - Complex Atrium Location

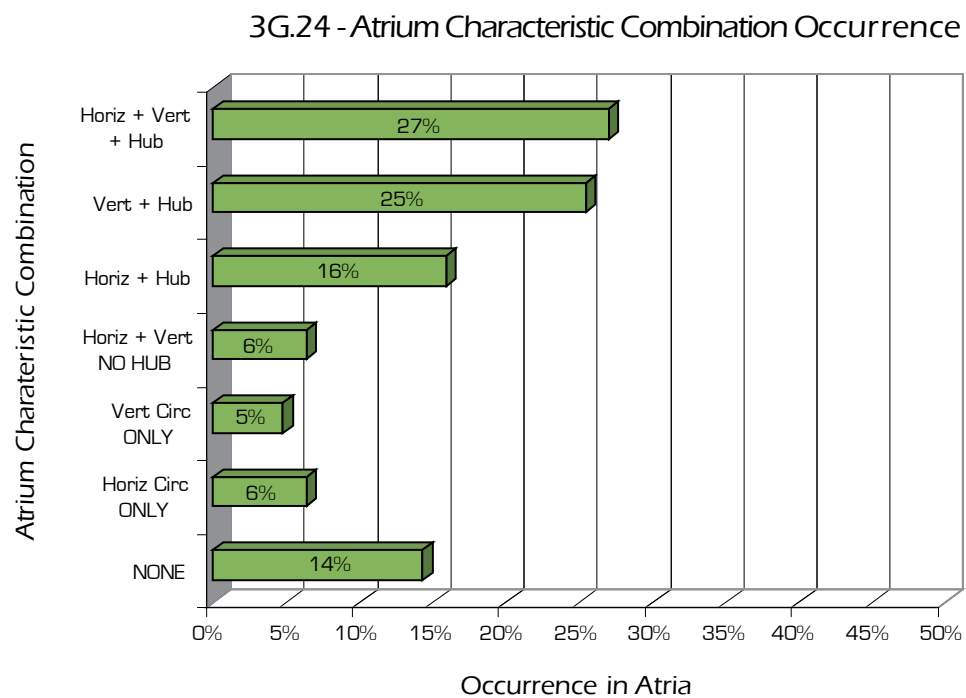
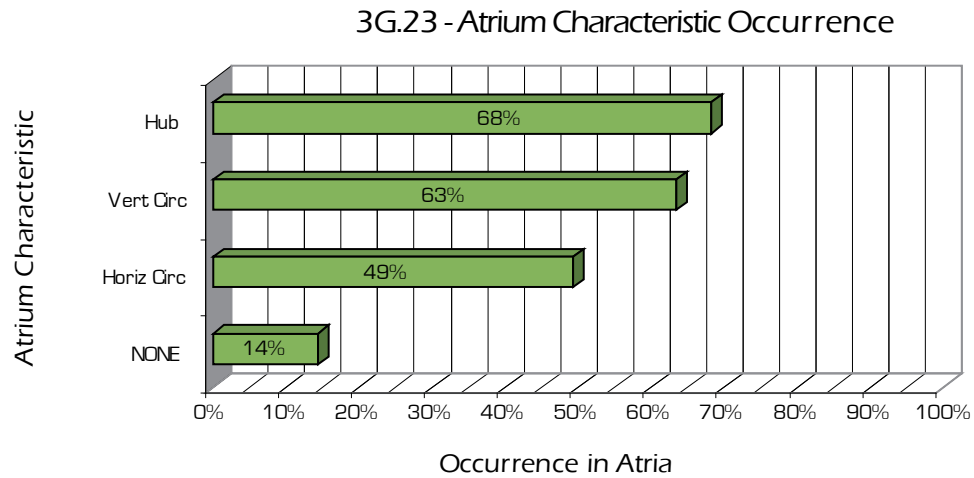
G.21 - Atrium Location vs Building Size



- Atrium Total
- Central Atrium
- Both Locations
- Perimeter Atrium

3G.22 - Atrium Location vs Building Height





To gather an understanding of how the atria were working within each building a breakdown of organization and circulation use was compiled in graph 3G.23. It was found that the largest percentage of instances maintained their atria as a hub for the building (68 percent). The next largest use of the atrium space was with the incorporation of vertical circulation within the atrium space (63 percent), while just less than half maintained the atrium for horizontal circulation at 49 percent. Lastly, nine atria (14 percent) were identified to have no organizational qualities, which would suggest that the atrium space was purely aesthetic in this regard. A further breakdown in organization and circulation combinations in graph 3G.24 found that the group of atria which maintained all three, building hub with both vertical and horizontal circulation were the largest occurring combination. With a few less instances, the combination of solely vertical circulation and building hub was found to be next most common. Refer to the same graph for the remaining combination occurrences.

Focusing in on the 'green' buildings, it was found that 17 out of the 18 buildings included an atrium space within their design. Exceeding the general survey inclusion rate of 61 percent by 33 percent to a rate of 94 percent, a strong correlation between 'green' design and atrium inclusion can be surmised. A further breakdown of the atria characteristics discussed in this section has been specifically noted in table 3.2 to address these buildings. The table of 'green' building shows a large majority of their atria as being located centrally and as being used as building hubs. The common central distribution of their location diverges from the overall survey, suggesting another 'green' building correlation, whereas finding that the majority of atria act as building hubs corresponds to the atria use shown in the overall survey. As well, a near split is seen between simple and complex atria, while almost eliminating the partial atrium (only one 'green' building maintains a partial atrium). The atrium type results set themselves apart from the overall survey, where large counts of partial atria were documented. The lack of partial atria within the 'green' building group could suggest an ineffectiveness of partial atrium for executing and maintaining sustainable characteristics. The specific findings related to sustainable characteristics of atria in both the overall survey and the smaller grouping of 'green' buildings will be outlined in the next three sections.

## ‘Green’ Building Atria Characteristic Table

Table 3.2

	Atrium	Atrium Type	Atrium Sub-Type	Location	Organize Use	Circulation Use
York Computer Science Building York University	Yes	Complex	Multi-Lateral	Centrally	Circulation	Horizontal
National Wildlife Research Centre at Nesbitt Bldg Carleton University	No					
School of Information Technology and Engineering (SITE) University of Ottawa	Yes	Simple	1 Sided	Perimeter	Hub	Both
Bahen Center for Information Technology University of Toronto	Yes	Simple	Linear	Centrally	Hub	Both
HP Science and Technology Center Centennial College	Yes	Complex	Multi-Lateral	Centrally	Hub	Horizontal
Technology Wing Southerland Campus Sir Sandford Fleming College	Yes	Simple	Linear	Centrally	Hub	Horizontal
Chemical Sciences Building Trent University	Yes	Partial	3 Sided	Perimeter	Circulation	Both
Science Building University of Ontario Institute of Technology	Yes	Complex	Multi-Lateral	Centrally	Hub	Horizontal
Centre for Environmental and Information Technology (CEIT) University of Waterloo	Yes	Simple	Closed	Centrally	Hub	Both
TEL Building York University	Yes	Complex	Multi-Lateral	Both	Hub	Both
University of Guelph-Humber Building Humber College	Yes	Complex	Multi-Lateral	Centrally	Hub	Vertical
Beamish Munro Hall \ Integrated Learning Centre Queen's University	Yes	Simple	Closed	Centrally	Hub	Vertical
School of Environmental and Natural Resource Sciences Sir Sandford Fleming College	Yes	Simple	Linear	Centrally	Circulation	Horizontal
Business and IT Building University of Ontario Institute of Technology	Yes	Simple	Closed	Centrally	Hub	Vertical
Centre for Manufacturing and Design Technologies Sheridan College	Yes	Simple	Linear	Centrally	Hub	Both
The Terrence Donnelly Centre for Cellular and Biomolecular Research (CCBR) University of Toronto	Yes	Complex	Multi-Vertical	Both	Circulation	Vertical
University Plaza Building Brock University	Yes	Simple	3 Sided	Perimeter	Hub	Both
The Leslie L. Dan Pharmacy Building University of Toronto	Yes	Complex	Multi-Lateral	Both	Hub	Vertical
	17	9 Simple 1 Partial 7 Cmplx	3 Closed 1 1-Sided 0 2-Sided 1 3-Sided 4 Linear 6 Multi-Lateral 1 Multi-Vert.	11 Cent 3 Perim 3 Both	13 Hub 4 Circul. 0 None	7 Both 5 Vertical 5 Horiz. 0 None



## Atrium Reuse Results + Analysis

## 3.3

The first atrium characteristic of conservationism examined is the ability of the atrium to assist in material conservation through reusability. This is first seen during the design and completion of buildings, acting as part of renovations and additions, and then after the design's completion, later in the building's life, during changes in ownership and building functions. This section has been subdivided to reflect the different project types to which these conservational traits apply; those pertaining solely to inclusion in additions and renovations, and those which pertain to all atria.

Initially the atrium can be included as part of additions and renovations to assist in the reuse of existing buildings (as outlined in section 1.6). Cumulatively the additions and renovations represent 29 percent, or close to a third of the buildings examined in the survey (as seen previously in 3G.4); eighteen building additions and twelve building renovations. Within these project types, there were found five building additions with atria and five building renovations with atria, as noted in graph 3G.9. At only 28 percent atria inclusion for building additions and 42 percent for renovation inclusion, it appears that renovations are more likely to use an atrium (as previously noted in section 3.2). Of those atria in the additions sub-category, four out of the five atria were found to actually use the atrium in a connecting capacity, linking the existing and additional building (see 3G.27 on the next page). Similarly, four out of the five atria found in renovations were added as part of the building renovation (also on 3G.27). Collectively the instances of connective adaptation and renovation adaptation represent 13 percent of the atria within the survey, split equally between both adaptations (graph 3G.25 on the next page). This is a small portion of the atria found in the survey and the assessment of an atrium's adaptation use in the particular area of new academic projects is limited as a result.

Based on the cases identified in the survey, both for additions and renovations, the likelihood of an atrium in either sub-category is low overall, resulting in a low occurrence of this conservative strategy. But, when an atrium is actually used, the atrium has a very direct role specifically related to the project's nature; as demonstrated by the four out of five cases in each sub-category.

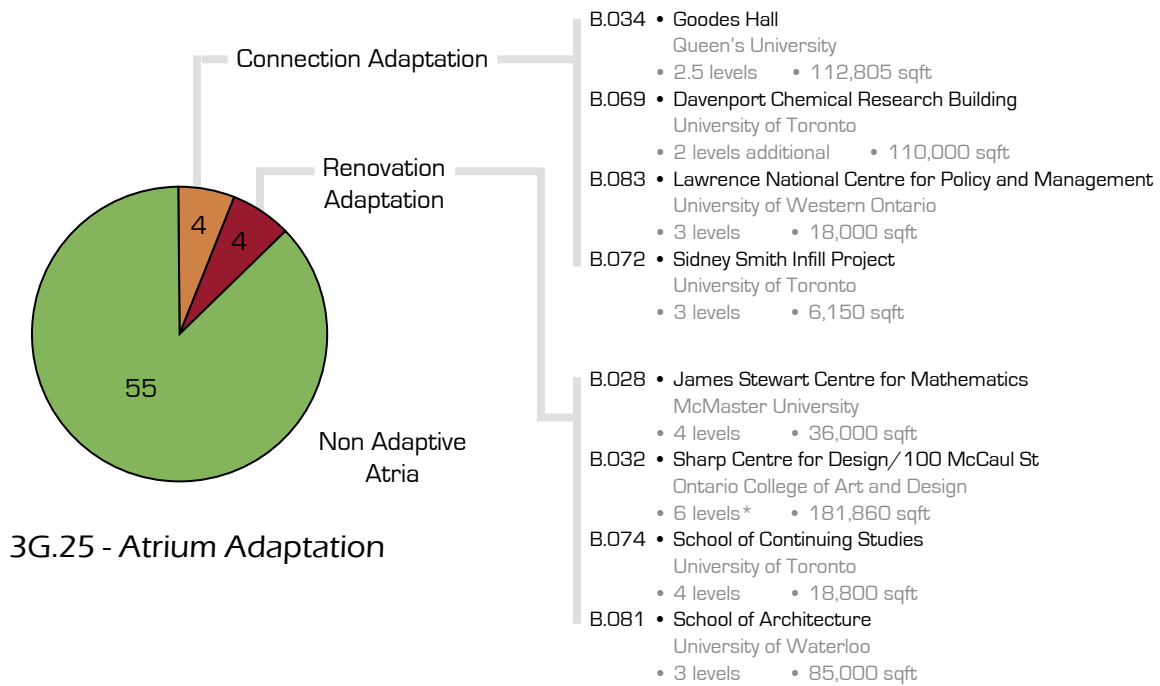
Also during the design of a building, the atrium can preserve existing historical building façades, which are adjacent to or adjoining the new building project. Within the



fig. 3.04 - The Davenport Chemical Research Building at the University of Toronto shows patches of brick which reveal the existing building as part of an addition which included this adaptive reuse atrium

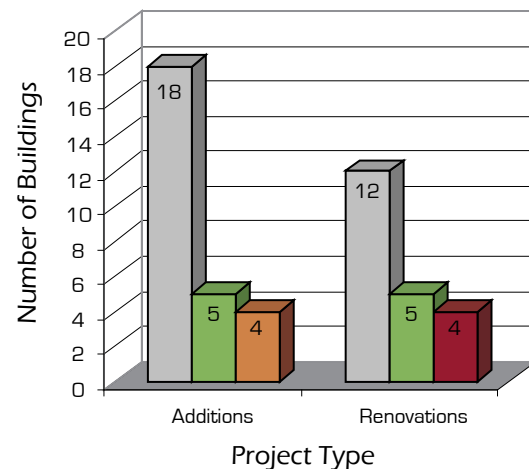


fig. 3.05 - The Lawrence National Centre for Policy and Management at University of Western Ontario preserves the historic building facade as part of an addition which included this adaptive reuse atrium



- Historic Preservation**
- B.083 • Lawrence National Centre for Policy and Management  
University of Western Ontario  
• 3 levels • 18,000 sqft
  - B.076 • Terrance Donnelly Centre for Cellular and Biomedical Research  
University of Toronto  
• 10 levels • 221,120 sqft

3G.27 - Project Type Comparison Chart

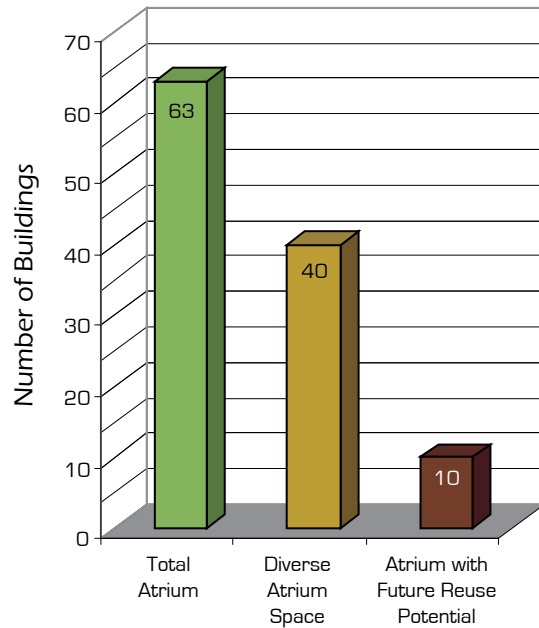


■ Surveyed Building  
 ■ With Atrium  
 ■ Connection Adaptation  
 ■ Renovation Adaptation

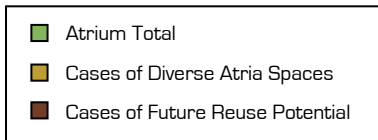
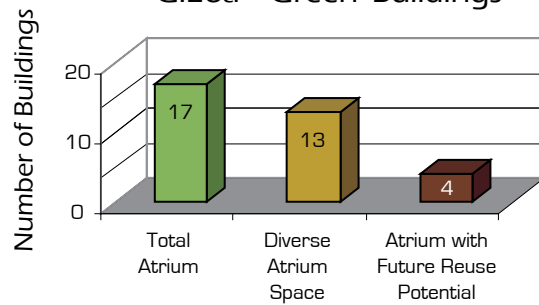
survey there are two instances of the preservation of building façades. This represents a mere 3 percent of the instances of atria (graph 3G.26). These are seen in the Lawrence National Centre for Policy and Management and the Terrance Donnelly Centre for Cellular and Biomolecular Research (CCBR). The Lawrence National Centre is a modern building addition to a classical stone building built just after the turn of the twentieth century. The addition retains and restores the adjoining façades using the inside of the atrium space which also connects to the modern building addition. Here the atrium is also an instance of connective adaptation. Whereas the CCBR is a completely new building which butts up against an existing building, and rather than covering up or losing the existing façade, preserves it using an atrium at the base of the new CCBR building. Since the CCBR does not join with the adjacent building, it is not seen as an addition, but nevertheless has preserved the classic façade in the process of constructing the new building.

The low occurrence in the study group reflects the few additions to classic buildings which could have been preserved, and thereby suggests the limitations of the preserving aspect of the atrium's conservational characteristic. This characteristic of conservationism is only as useful as it pertains to construction of historically significant buildings, for which there are overall few opportunities.

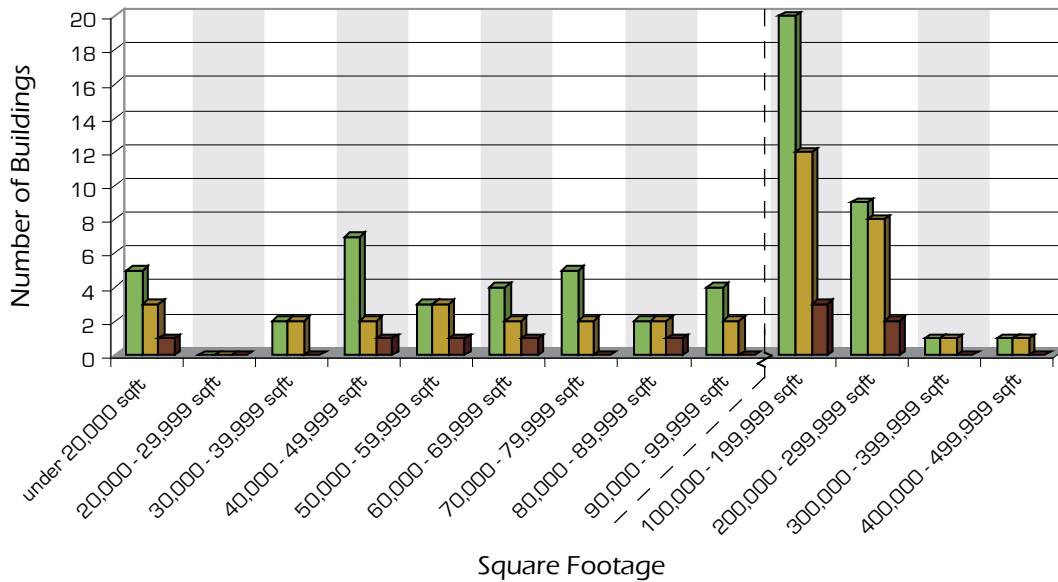
The reusability which the atrium can inspire and perform also occurs after the conclusion of the initial design and building completion. By providing a diverse space to accommodate many differing functions and/or easily allowing for the atrium to adapt to changes, the atrium can facilitate the reuse of the building over the course of time (as outlined in section 1.6). These instances are defined in section 2.2 Survey Criteria, where a 'diverse space' is seen as a multi-function space, which can be used or set-up for different functions: informal/formal gatherings, gallery, presentations, meeting space. 'Future reuse' is defined as the potential for the atrium space to change its program in response to building renovation or change in building occupant or building use. By using these general concepts it was found that 40 instances out of the 63 atria (graph 3G.28) were seen as a diverse space (63 percent). The diversity in atria is a close majority, suggesting it is a prevalent conservational characteristic although far from a guarantee. Conversely, only 10 atria of the 63 were seen as demonstrating a potential for future reuse (16 percent), also seen in graph 3G.28. It should be noted that atria which maintained significant circulation routes were not counted in this criterion, even though the circulation would be

3G.28 - Cases of Atrium Diversity  
and Future Reuse

G.28a - 'Green' Buildings



## 3G.29 - Reuse vs Building Size



- Atrium w/ Diverse Space
- Atrium w/ Future Reuse Potential
- Atrium Total

## 3G.30 - Reuse vs Building Height

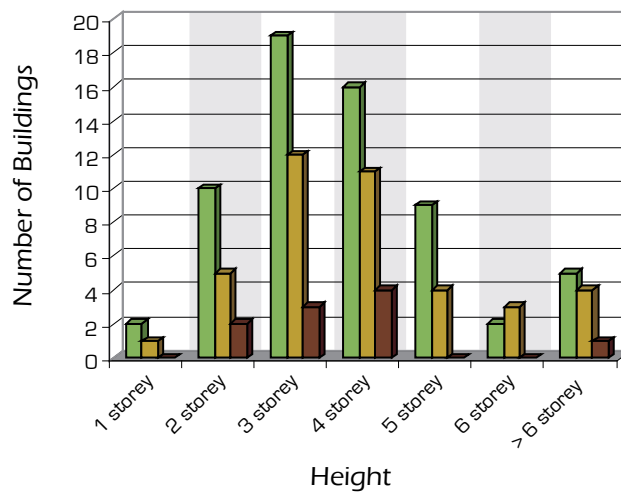




fig. 3.06 - The central atrium space at the Science building at the University of Ontario Institute of Technology offers a diverse space which can be used and set up for many different occasions

reused with changes in the building, this criterion was looking for a more significant capacity for reuse. Unfortunately the future reuse potential is not as common, and occurs in any instance where specific program is currently implemented within the atrium, and therefore it is seen as having future reuse potential for hosting an alternative specific program. Furthermore, this criterion may be setback by the use of many atria for circulation, which limits the future adaptability of the atrium space.

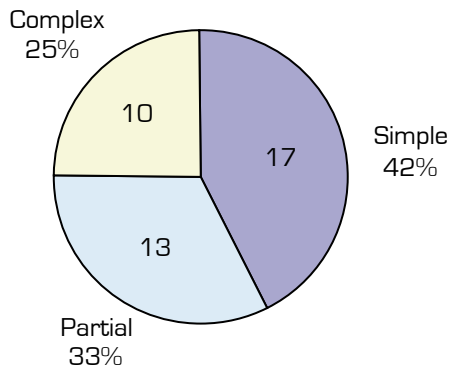
When comparing atrium diversity against building characteristics, such as size and height, no discernable patterns of correlation appear. The diversity of atria was dispersed among the comparisons and corresponded to overall building quantity trends in a particular size or height category. (See graphs in section 3G.29 + 30) As for the future reuse there was no noticeable pattern or tendency found when looking at building size, there was however a noticeable grouping of future reuse in the height comparison. The majority of the future reuse occurred between 2 and 4 storeys. Unfortunately with such a small count (10 instances) it is hard to tell if this is a viable trend, as this pattern also coincides with the greatest quantity of buildings which occurs in the 2, 3, and 4 storeys, and may amount to simply occurring where there is the greatest chance.

When examining the breakdown of atria type and location within diverse atria, the results are fairly similar to the overall survey. Small declines in the percentages of partial atrium type and perimeter located atria were the only differences found (graphs 3G.31 – 32 on the opposite page). The breakdown of organization within diverse atria is comparable to the overall survey with the exception of the atrium's use as a building hub which is greater at 80 percent (graph 3G.33 on the opposite page). This result could be expected, as a diverse and versatile space capable of handling a variety of activities would be a logical central hub for a building.

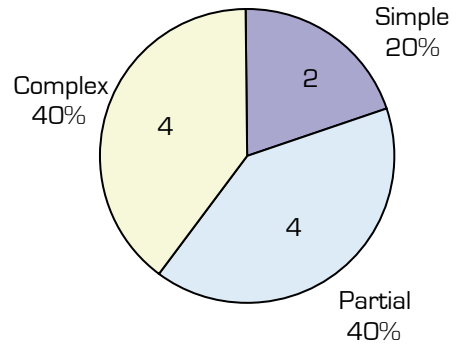
Apparent deviations are seen in the future reuse breakdowns, where the simple atrium type is reduced from 36 percent in the overall survey to 20 percent (see graph 3G.34). The breakdown for future reuse in atrium location also shows a decline in instances of perimeter located atria (see graph 3G.35). The organizational breakdown of future reuse in atria is noticeably different from everything else in the survey. It shows a 40 percent occurrence in all four criteria (see graph 3G.36). Future reuse atria have much lower organizational use occurrences of hub, vertical, and horizontal circulation compared to the general survey. And most strikingly, they show the highest occurrence of an atrium with no organization at 40

## Reuse: Breakdown

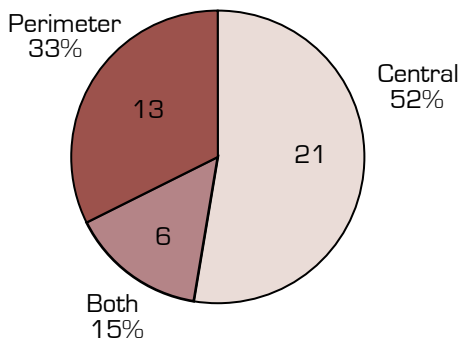
Graph 3G.31 - 36



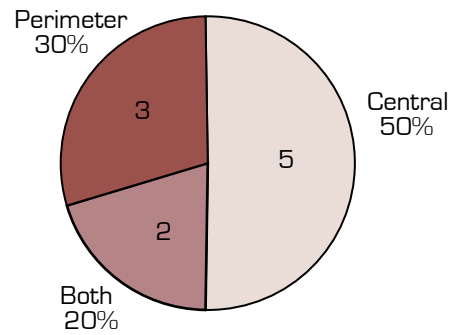
3G.31 - Atrium Diversity vs Type



3G.34 - Future Reuse vs Type

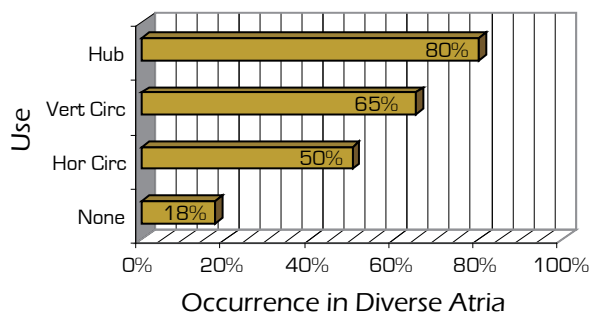


3G.32 - Atrium Diversity vs Location

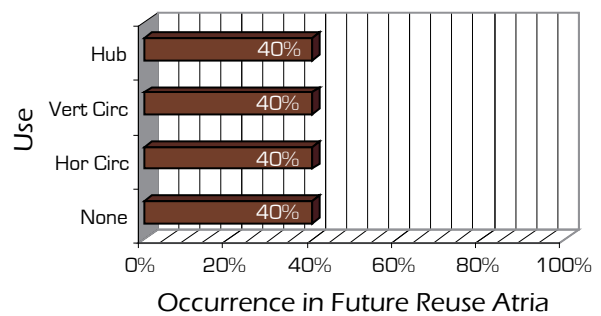


3G.35 - Future Reuse vs Location

3G.33 - Atrium Diversity vs Organizational Use



3G.36 - Future Reuse vs Organizational Use





percent, much higher than the overall survey at 14 percent. This all can be attributed to the role the atrium space plays within the building program. In order to be reused in the future, a specific program is most likely to be currently accommodated within the atrium, rather than circulation or a building hub, which tend to be a more diverse use of space and less likely to be changed to accommodate in future uses.

#### 'Green' Building Observations

There are no self proclaimed 'green' buildings which are additions or renovations, and therefore none employed any of the adaptive qualities of the atrium. Although two cases, which are unique, showcase complete new buildings that are infill projects which do come into contact with the surrounding buildings. The first is the CCBR, and as mentioned above, it uses its atrium to preserve the historical façade to which it abuts. The other is the Beamish Munro Hall at Queen's University which was built between three existing buildings. Although it maintains its autonomy, its design left provisions to maintain daylighting through the new building to the façades of the existing adjacent buildings. As a result of the types of projects self-identified as 'green', namely completely new buildings, these 'green' buildings are not well represented in the first area of reuse.

When examining the 'green' buildings' performance in the second area of reuse, 13 of the 17 'green' buildings (seen previously in graph G.28a) are seen to maintain diversity in their atria (76 percent) which is higher than the occurrences in the overall atria survey. Likewise, 4 of the 17 'green' buildings are seen to have future reuse potential (29 percent). Therefore 'green' buildings are 10 percent more likely to maintain diversity in the atrium spaces and twice as likely to have future reuse potential.

## Daylighting Results + Analysis

## 3.4

The second atrium characteristic of conservationism examined is the ability of the atrium to introduce sunlight into the building to conserve energy. It helps in energy conservation by reducing the need for artificial lighting, while potentially providing a healthy full spectrum of light. Simultaneously, sunlight can be harnessed to offset building heating loads, as incoming daylighting also provides solar gain (both outlined in section 1.6). With a strong tradition of daylight incorporation in atria there are many effective precedents for the control of sunlight and its effective daylighting application.

As expected due to the nature of atria and their inclusion of glazing, it was found that almost all buildings, 61 out of 63 atria, maintained daylighting in their design (97 percent) see graph 3G.37. The two exceptions did have glazing, but it was seen to be not useful enough to provide daylight for either lighting or solar gain. However, while the incorporation of glazing and thus daylight seem tied to the atrium form, further refinement to eliminate glare, limit unwanted solar gain or otherwise actively control daylighting was attempted by only 16 of those 61 buildings. Though 4 additional buildings had solely north facing glazing, acting to reduce solar gain and control daylight by eliminating direct sunlight penetration, they fall short of fully capitalizing on potential savings by not allowing for the solar gain during winter when it could be useful. Even when we disregard the limitations of that approach, it can be said that at best 20 out of the 61 buildings (33 percent) with daylighting are attempting to control the daylight so that it can be used to the building's advantage at all times of the day and year. The remaining buildings may have daylighting with a potential to reduce artificial lighting and heating demands and thus energy consumption, but without any control they may in fact be causing inadvertent increased cooling loads in the summer. In climates like Southern Ontario, such cooling loads are potentially a greater gross increase in energy use, forgoing any energy conserving measures.

A large majority of the atria surveyed have vertical glazing both exclusively and in combination with top and clerestory glazing (see graph 3G.38). Unfortunately the least frequent occurrence in the survey is the use of clerestory glazing, which is the most useful for bringing daylight into a building without large amounts of glare and solar gain: an easy way to control daylighting. Further examination of the orientation of clerestory and vertical glazing reveals a fairly even distribution across

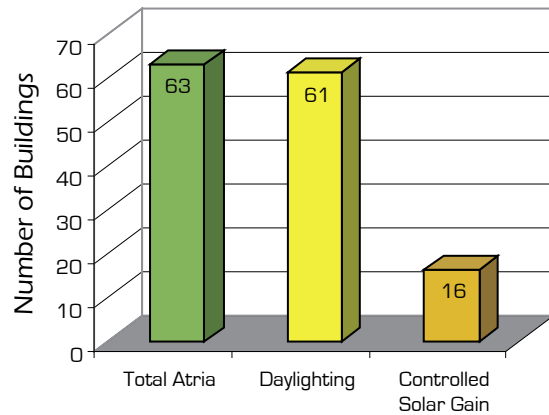


fig. 3.07 - The central atrium space at the Guelph-Humber building allows daylighting through the top clerestory glazing

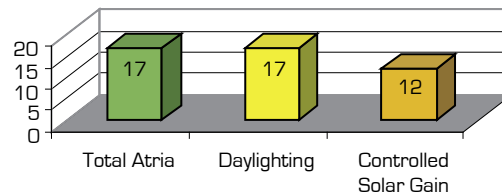


fig. 3.08 - Sunshade detail at the Technology Wing at Sir Sanford Fleming College

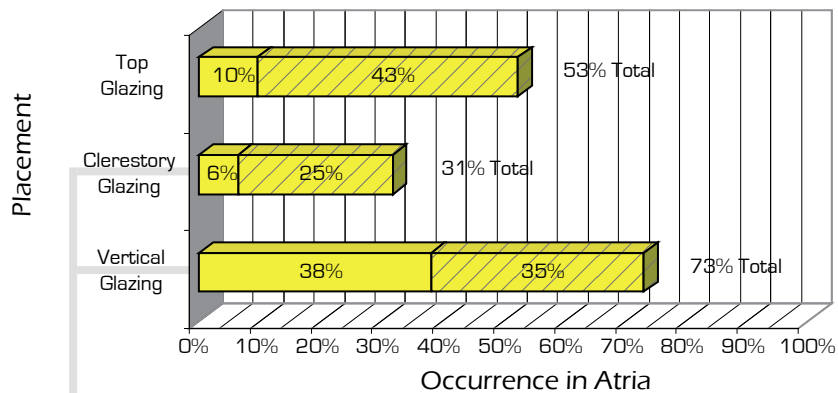
3G.37 - Daylighting



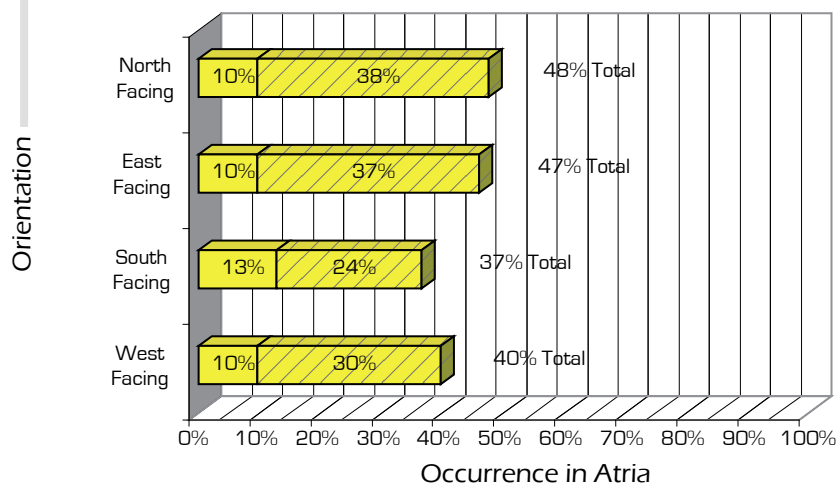
3G.37a - Daylighting in 'Green' Buildings



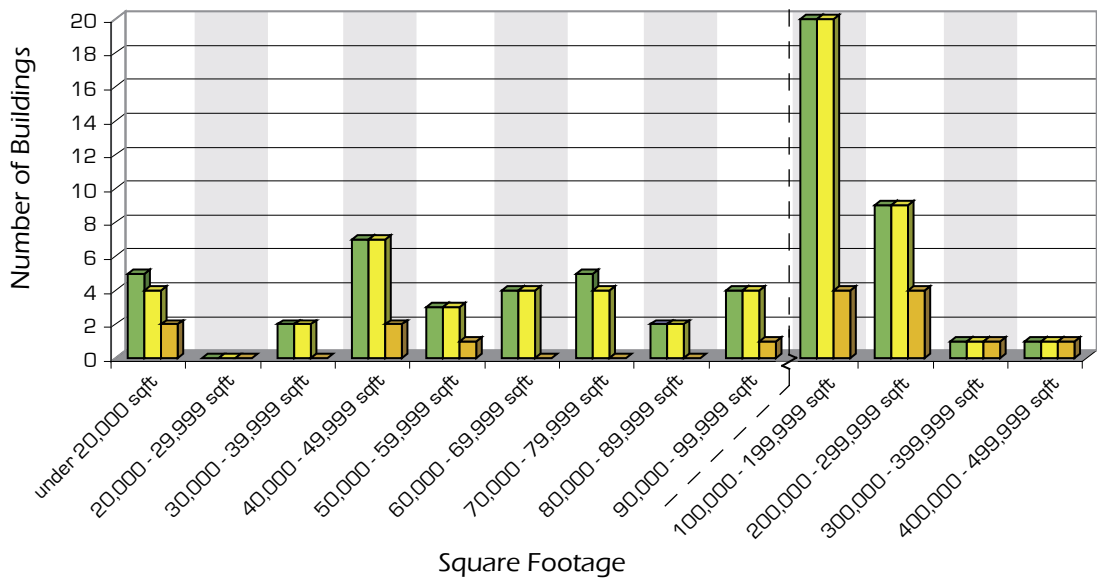
3G.38 - Glazing Placement



3G.39 - Glazing Orientation

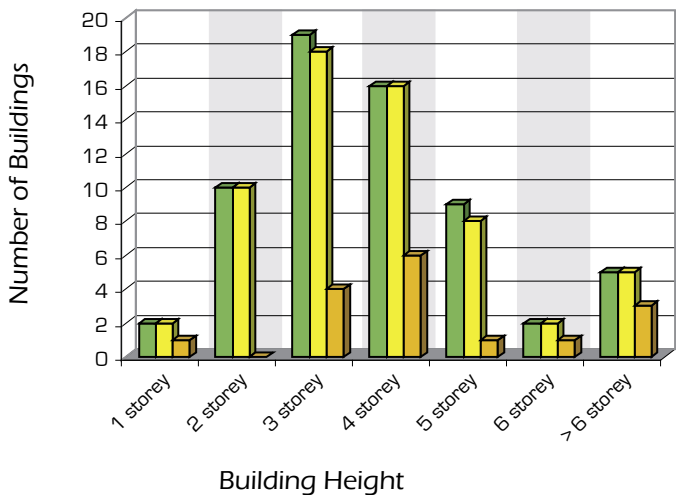


3G.40 - Daylighting vs Building Size



- Atrium w/ Daylighting
- Atrium w/ Controlled Solar Gain
- Atrium Total

3G.41 - Daylighting vs Building Height



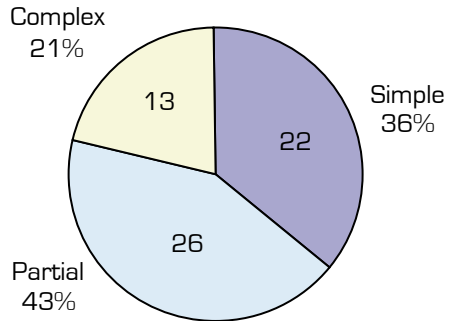
each orientation (see graph 3G.39). The strongest individual showing was in south facing glazing, while the leading collective occurrences (both solely and in combination with others) of vertical glazing were to the north and east orientation, 48 and 47 percent respectively. The uniform distribution of glazing orientation suggests no deliberate strategy through strategic avoidance or selection: one could speculate that most glazing simply fell where layout permitted. It should be noted that despite the potential of Heliostats, mirrors and other daylighting redirection tools, no such examples were found in the buildings surveyed.

When comparing the daylighting findings against building characteristics, such as size and height, no discernable patterns of correlation appear. (See graphs 3G.40 + 41) Likewise there was no noticeable pattern or tendency found when looking at controlled solar gain and those same building characteristics. As there are many factors involved with the control and management of daylight, it's not surprising that a direct relationship with the size and height of the building can not be drawn. Whereas, the value and need for daylighting should increase with the size of a building where a smaller ratio between the perimeter of the building and internal space exists. The relief of an internal atrium to bring more daylight into the building would be ideal. However this study has not attempted to measure this value or need.

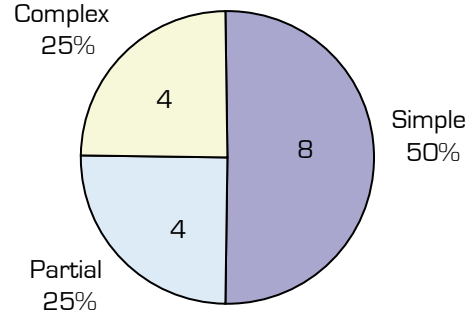
When examining the breakdown of atria type and location within the atria with daylighting, the results are very similar to the overall breakdown as the data range is essentially the same, less only two buildings which did not satisfy the demand for daylighting (graphs 3G.42 – 44 on opposite page) When looking at controlled solar gain however, more distinct trends emerge such as greater occurrences of controlled solar gain in simple atria (50 percent) compared to the overall survey of only 36 percent (see graph 3G.45 on opposite page) Similarly controlled solar gain is more likely to occur in centrally located atria (62 percent) compared to the survey occurrence of 51 percent (graph 3G.46 on opposite page) Lastly, within the organizational breakdown, controlled solar gain (see graph 3G.47 on opposite page) closely reflects the trends seen in the overall atria breakdown (previously in graph 3G.23) showing no differing tendencies of significance.

## Daylighting Breakdown

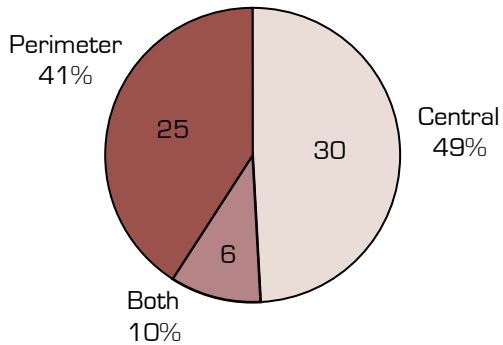
Graph 3G.42 - 47



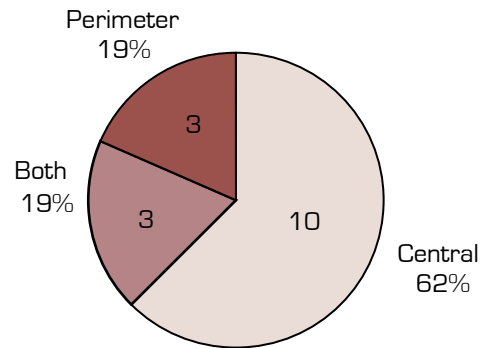
3G.42 - Daylighting vs Type



3G.45 - Controlled Solar Gain vs Type

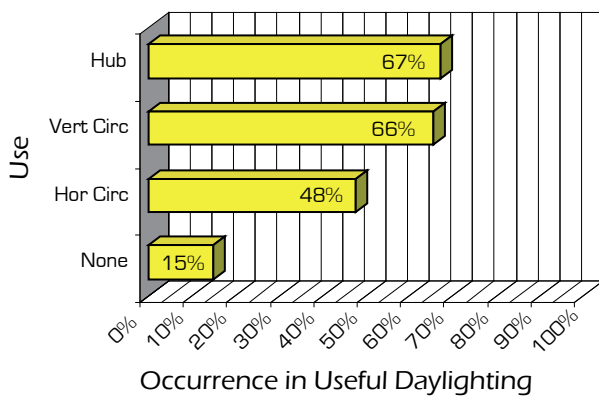


3G.43 - Daylighting vs Location

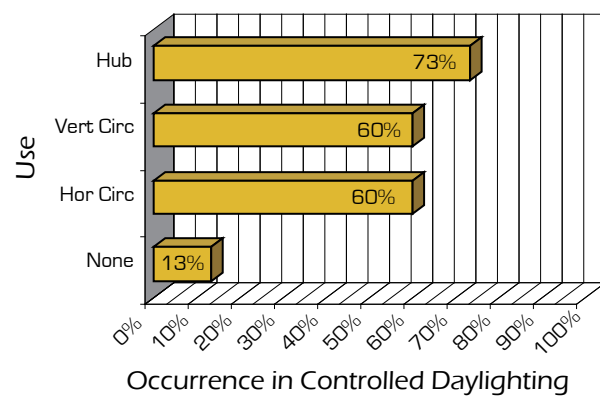


3G.46 - Controlled Solar Gain vs Location

3G.44 - Daylighting vs Organizational Use



3G.47 - Controlled Solar Gain vs Organizational Use



## 'Green' Building Observations

Not surprisingly all 17 'green' buildings with atria maintain daylighting (graph 3G.37a). There is also a strong showing of controlled solar gain in the 'green' buildings, as 12 of the 17 buildings (70 percent) have demonstrated some form of controlled solar gain. This is to say that the inclusion and control of daylighting in a 'green' building is three times as likely as in a building not identified as such. Collectively, these buildings constitute 75 percent of the controlled solar gain occurrences found within the survey. These results begin to show a large rift between those buildings which are deliberately attempting to conserve and the rest of the buildings which are not.



The last atrium characteristic of conservationism examined is the ability of the atrium to create passive air movements to conserve energy. As discussed previously (section 1.6) the atrium has several possible applications as part of a passive air strategy within a building. Acting to facilitate air movement by taking advantage of air stratification with a chimney or stack effect, atria can help conserve electricity by reducing the need for constantly running air handling units to circulate air for ventilation. Alternatively, by acting as an air reservoir to precondition air as well as in exhausting air through vertical movement for cooling the building, atria can work to offset heating and cooling loads.

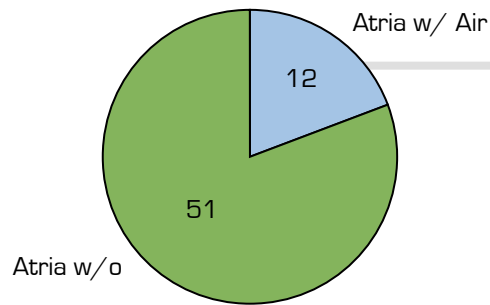
Of the 63 buildings with atria it was found that 12 (19 percent) were designed to use passive means to create air movements for some part of the year (graph 3G.48) Of these 12, eleven accomplished this by using the atrium as an exhaust/cooling atrium: the hot air rises and escapes from the top of the atrium, this movement is used to either exhaust used air and/or reduce the heat within the building (graph 3G.49) The twelfth atrium with a passive air strategy uses the atrium as a pre-conditioning atrium where fresh air is directed into the atrium to be heated through solar gain and is then skimmed off the top (as warmer air) and redirected to the rest of the building. The overall passive air strategy count has the weakest showing of the three conservational aspects. These results confirm notions which consider passive air strategies to be the energy conserving aspect hardest to design and accomplish, with the smallest payoff relative to effort input. Furthermore, of the twelve passive air strategy atria, a quarter (three cases), used solar chimneys to amplify the air stratification to encourage the movement of air.

When comparing the passive air strategy findings against building characteristics, there appears a tendency for application to occur in larger buildings, as all but two cases occurred in buildings 100,000 square feet or larger (see graph 3G.50). This could be the result of a correlation between larger buildings maintaining larger atrium spaces that are able to move more air, making the design of passive air strategies more effective and worthwhile. Conversely, when running a comparison between atrium height and passive air strategy inclusion, there are no discernable patterns of correlation (see graph 3G.51) This absence is curious, as one might expect to find a relationship between a higher atrium being able to maximize

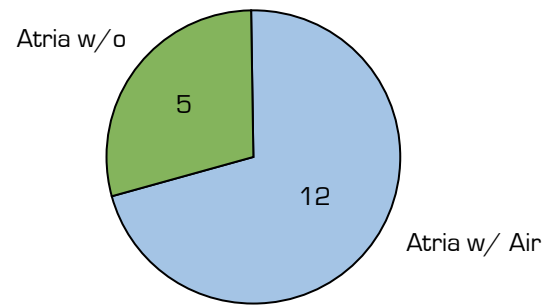


fig. 3.09 - A rising stone clad chimney which acts as a thermal chimney to move air through the building at Sir Sanford Fleming College Technology wing

## Passive Air Strategy

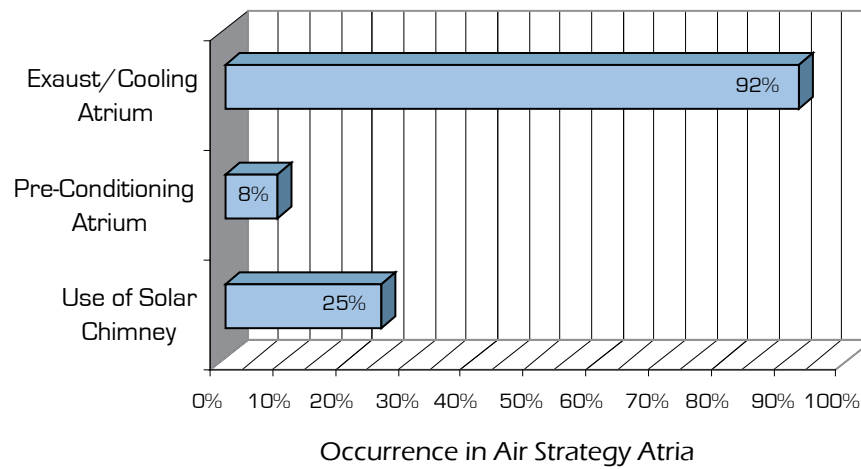


3G.48 - Passive Air Strategy

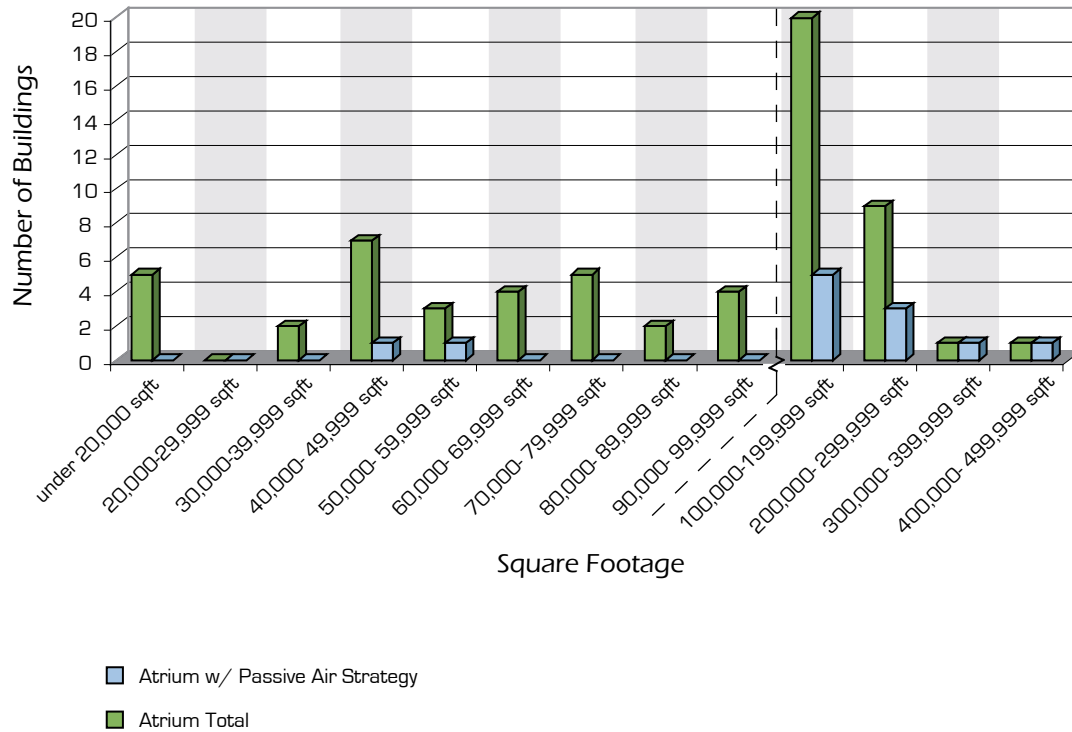


3G.48a - Green Building  
Passive Air Strategy

3G.49 - Passive Air Strategy Characteristics



## 3G.50 - Passive Air Strategy vs Building Size



## 3G.51 - Passive Air Strategy vs Building Height

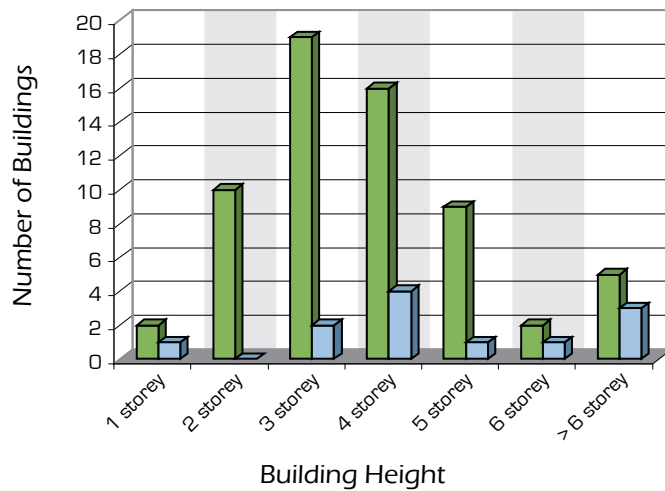




fig. 3.10 - Mechanically operated glazed vents atop the east atrium at the York University Computer Science building, can release exhaust air using the force of stack effect



fig. 3.11 - Large ducts take sun warmed air from the top of the atrium to redistribute throughout the building at University of Ottawa's SITE building

the stratification of air created, and passive air strategies which in turn could take advantage of the greater stack effect and thus greater forces to move air.

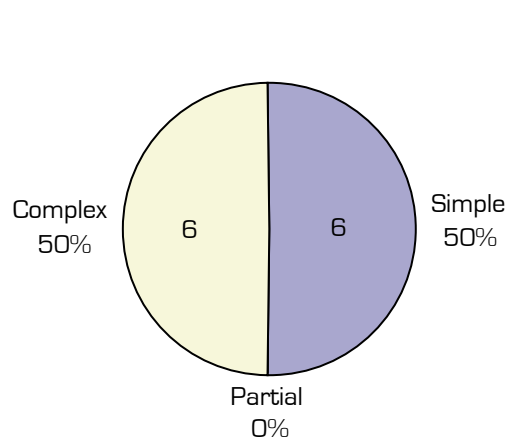
Examining the breakdown of atria with passive air strategies reveals an even split between simple and complex atria, entirely excluding partial atria from this breakdown (see graph 3G.52 on opposite page). This stands in contrast to the overall survey breakdown with a distribution of 36%, 21% and 43% for simple, complex and partial atria respectively. The absence of partial atria from passive air strategy atria should be expected as the atrium is required to be connected with the entire building to be effective in passive air movement. Similarly this tendency is confirmed by the large proportion of passive air strategy atria being located centrally in their building.

As seen in graph 3G.53 (opposite page), the majority of passive air strategy atria (67 percent) are located in the centre of the building, with the next most common occurrence being a combination of both central and perimeter, and only one atrium located exclusively along the perimeter. This perimeter atrium is the pre-conditioning atrium, whereas all the other central or combination atria are exhaustive/ cooling. Again, the common central location should be expected as the atrium is more easily connected with the entire building to be effective in passive air movement.

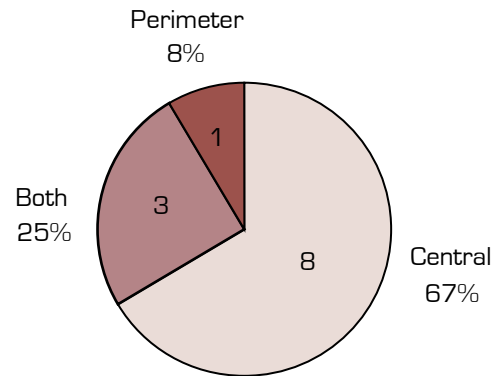
Within the organizational breakdown of the passive air strategy atria (see graph 3G.54 on opposite page) a few minor deviations are seen from the overall survey (previously in graph 3G.23). There is a slight increase in the likelihood of the atrium being a hub within the building organization, there is also a slight shift between vertical and horizontal circulation: there is a greater tendency for passive air strategy atria to include horizontal circulation than vertical which contrasts with the overall breakdown where it is more likely that the opposite be true. There are no passive air strategy atria which do not use their atria in some organizational application in the building whether it be vertical circulation, horizontal circulation or as a building hub: all passive air strategy atria use their atrium for one or more of the organizational characteristics. These results are not so much reflective of the passive air strategy design, as much as they are a reflection of the design intent and the holistic incorporation of the atrium design. Passive air strategy within an atrium can be seen as the most developed aspect of its conservationism; as a result the atrium plays a very significant role in the building and is connected to it in many areas.

## Passive Air Strategy

Graph 3G.52 - 54

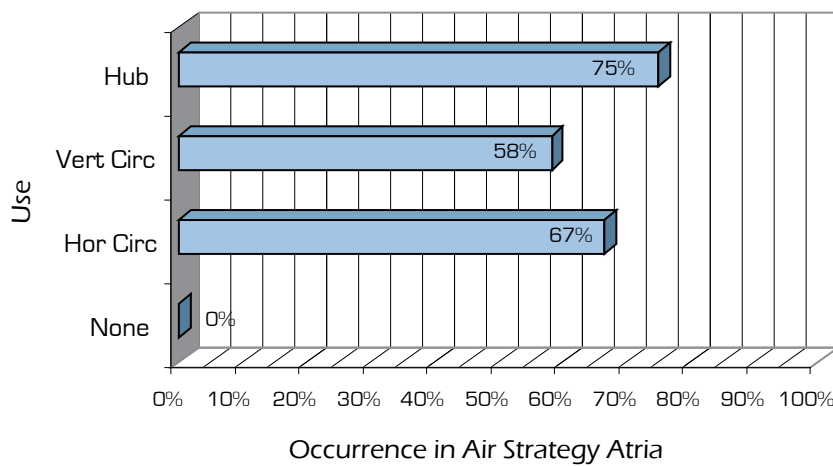


3G.52 - Air Strategy vs Type



3G.53 - Air Strategy vs Location

3G.54 - Air Strategy vs Organizational Use



## 'Green' Building Observations

All of the passive air strategy atria are apart of the group of self identified 'green' buildings; this would strongly suggest that passive air strategies require a great degree of planning organizing and designing (referring to graph 3G.48a) A strong desire to tackle 'green' building systems must be identified so that more involved strategies, like passive air movement, can be incorporated early on in the design and fully integrated into the building to ensure effectiveness as a sustainable tool. This further suggests that passive air strategies are only for those looking to commission, design, and build a 'green' design and those who wish it to be recognized as such. While creating an effective passive air movement atrium appears to be more involved than other strategies (i.e. daylighting, building reuse and organization) it seems to be an effective tool to gage the willingness of designers and clients to go beyond minimal efforts at building sustainability, and attempts to reach the next level of environmentally conscious design. It is worth noting that self identified 'green' buildings were almost 3 times more likely to incorporate controlled daylighting as compared to the general atria group (12 of 17, as opposed to 16 of 63) and 6 times more likely when 'green' buildings are excluded from the overall sample. All of these tendencies continue to show a much divided relationship between the buildings which are deliberately attempting to conserve energy and the rest of the buildings which are not.

In each of the previous three sections, an area of atrium conservationism has been broken down and examined individually; this section will look at the atrium conservational characteristics as a whole. Bringing all three areas together will create a clearer image of the conserving atrium characteristics' progression over time and their mutual relationships.

To get a general idea of how the atria in the survey shape up, the conservational characteristics were graphed over the course of time to note any general changes, and more specifically to discern if any one characteristic is becoming more dominant as a possible reflection of the growing acceptance and incorporation of 'green' and sustainable architectural ideas. Shown in a series of three graphs (3G.55 – 57 on the following page) the frequencies of each characteristic are graphed and can be compared to one another. As previously noted in the individual results, there are strong showings in diversity of atrium space and daylighting coming into atria. Further examination of each area of conservationism (same graphs 3G.55 – 57) reveals that each area has a similar relative pattern in the values for each year: an increase towards 2003 -2004 followed by a decline. This resembles the pattern previously seen in graph 3G.6 – Annual Distribution, which graphs the number of buildings and general number of atria over time. This suggest that there is a consistent percentage occurrence for each atrium conservation characteristic, which is shown in the line graphs behind the bar graphs in the series of three graphs 3G.55 – 57 on the following page. Although the line for each characteristic does vary slightly, generally they could be seen as consistently occurring in academic buildings. Annual percentage for each characteristic similarly reflects the study percentage in each of the three previous sections. These graphs show no apparent increase in conservational characteristics when it comes to atria in academic buildings, despite the continued and growing awareness and endorsement of conserving, 'green' and sustainable design. As the first year surveyed, 2000 ranks low for all areas of conservationism, and thus it could be suggested that 2001 was a year when conservationism in atria and 'green' building first began to appear, but this is highly unlikely and without previous information is inconclusive.

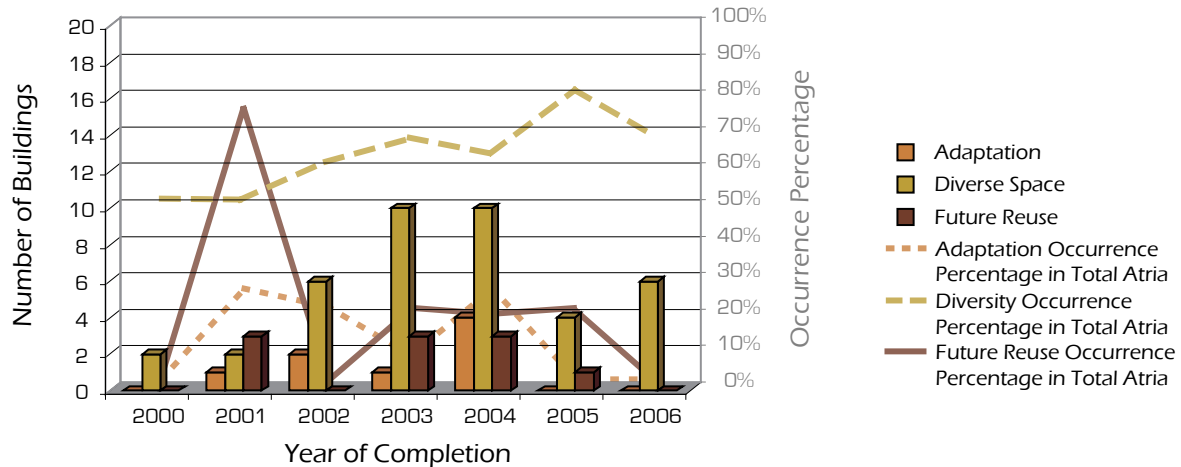
The previous three sections have shown the occurrence of each conservational characteristic, but to better identify what combinations are occurring, the totals are compiled into four graphs of conservational characteristic combinations:

**Survey Occurrence Percentage**

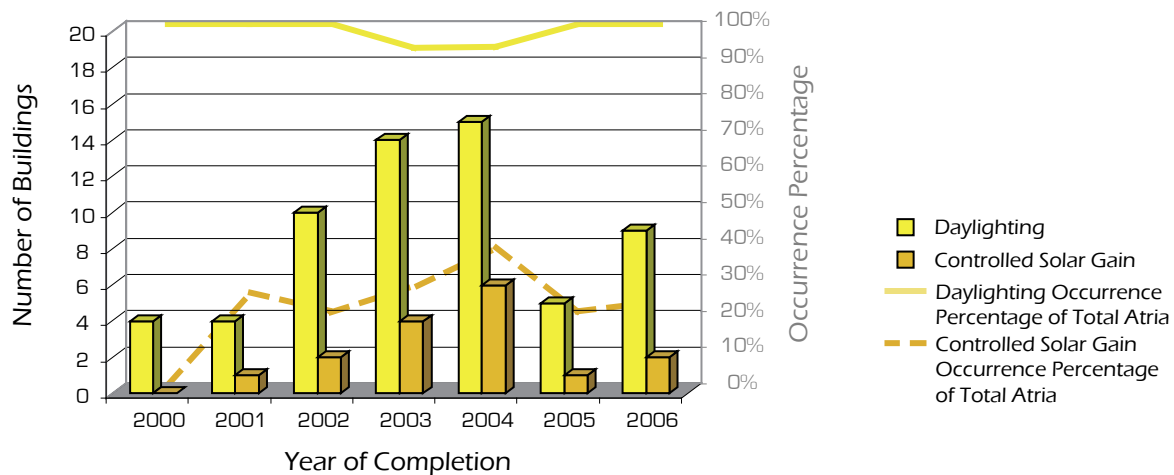
Adaptation	13 %
Diverse Atrium Space	63 %
Future Reuse Potential	16 %
Useful Daylighting	97 %
Controlled Solar Gain	25 %
Passive Air Strategy	19 %



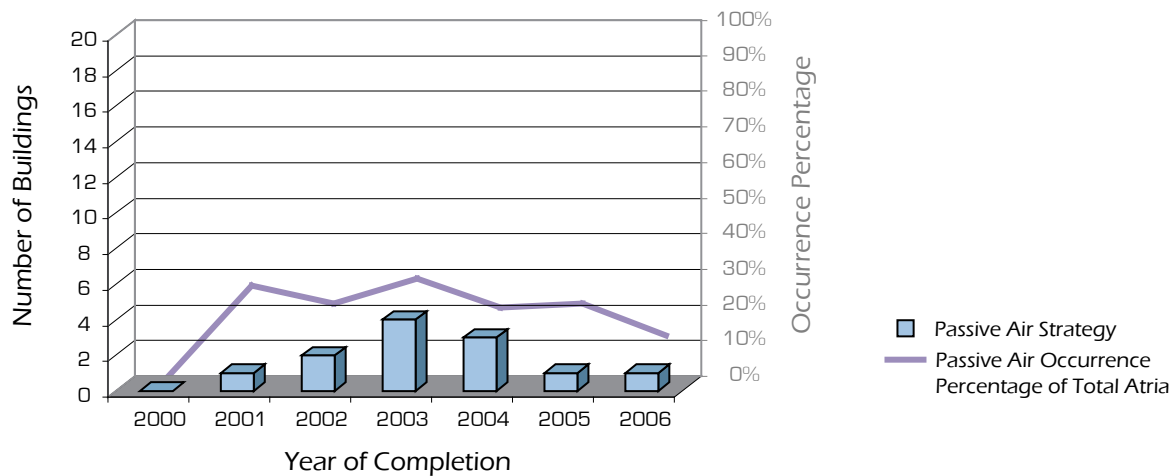
3G.55 - Reuse Cases



3G.56 - Daylighting Cases



3G.57 - Passive Air Strategy Cases



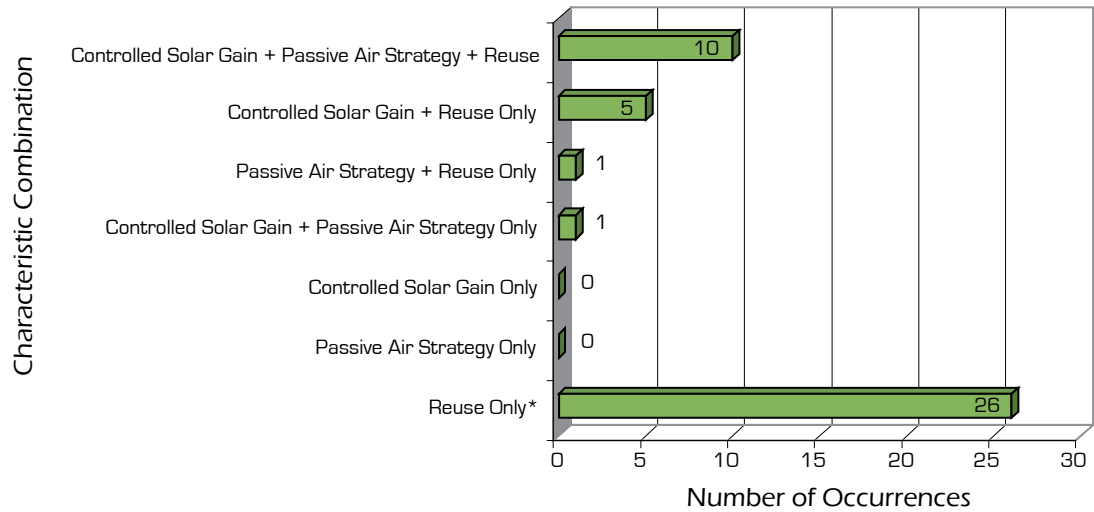
Conservation Combinations, where combinations of the three traits are identified; Most Frequently Occurring Combinations, in which the most common occurring combinations are further broken down to elaborate on which specific reuse characteristics accompany the energy conservational characteristics; Material Conservation Combinations, where the reuse characteristics combinations are compared against one another; and Energy Conservation Combinations, where controlled solar gain and passive air strategy combinations are identified. To simplify the combinations, the daylighting criterion was removed as almost all atria (except two) maintain this characteristic and its presence can therefore be assumed. As well, in the overall Conservation Combinations (graph 3G.58) the reuse characteristics are grouped together as one trait, and then later broken down with only the most frequently occurring combinations in graph 3G.59 and further compared against each other in their own graph (3G.60).

When looking at the overall Conservation Combinations (graph 3G.60), two things become apparent: firstly, that there are a lot of atria with Reuse only, and secondly, that there is a high occurrence of two or three characteristics occurring simultaneously (showing the tendency for the simultaneous occurrence of more than one characteristic). After the instances of Reuse only, the next most common occurrence is the combination of all three: as previously noted, when examining 'green' buildings, this confirms the tendency for a big gap between those buildings which use their atrium for conservation and those which do not. To elaborate on which specific reuse conservational characteristic was paired up with the energy conservational characteristic, graph 3G.59 shows the frequent occurrences and identifies which and how many reuse characteristics were used. Through this breakdown it is seen that the diverse atrium trait is the most common trait to be found in combination with other conservational characteristics, as well as the most common individually (3G.60).

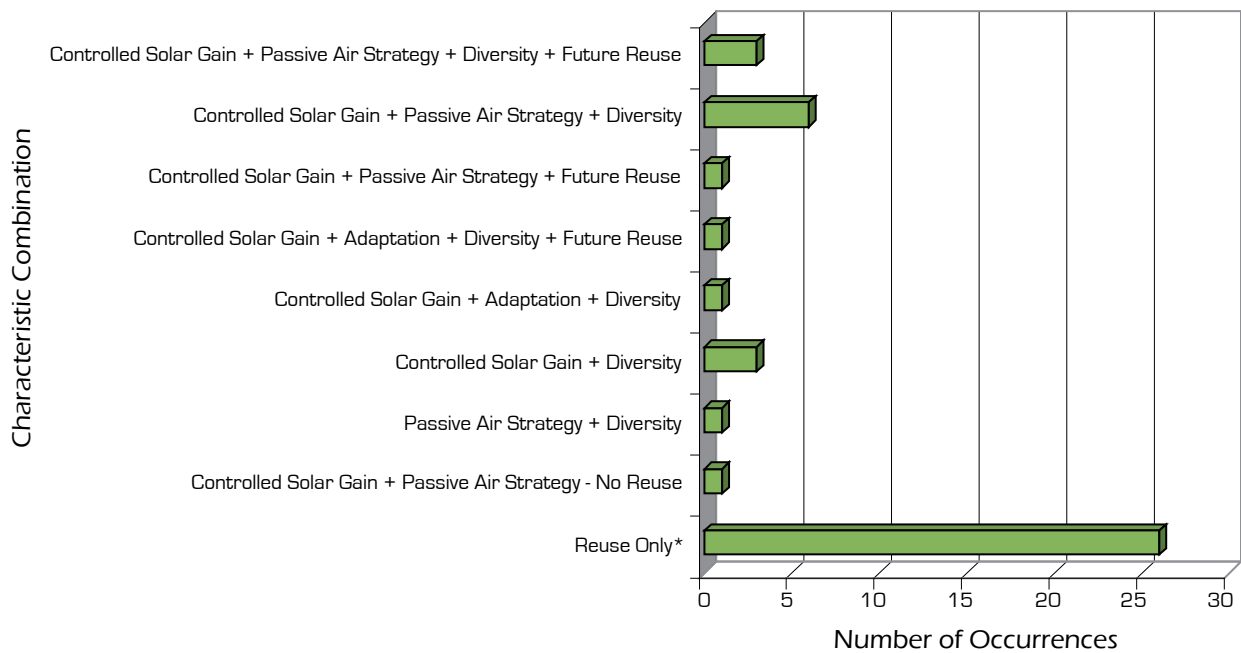
To further examine the many instances of reuse, graph 3G.60, breaks down the reuse characteristic into its different aspect combinations. It becomes clear that the presence of diversity alone within an atrium does occur often and largely contributes to the reuse results found in the previous graph 3G.58 and 3G.59. The tendency for frequent occurrences of diverse atria may be purely coincidental, in light of the trend noted above for a characteristic to appear in combination rather than alone; the many occurrences of diversity in atria may reflect heavily on the atrium-building relationship in terms of program and organization, resulting from the need

## Conserving Characteristic Combinations 1

3G.58 - Conservation Combinations (Amalgamated Reuse)



3G.59 - Most Frequently Occurring Combinations

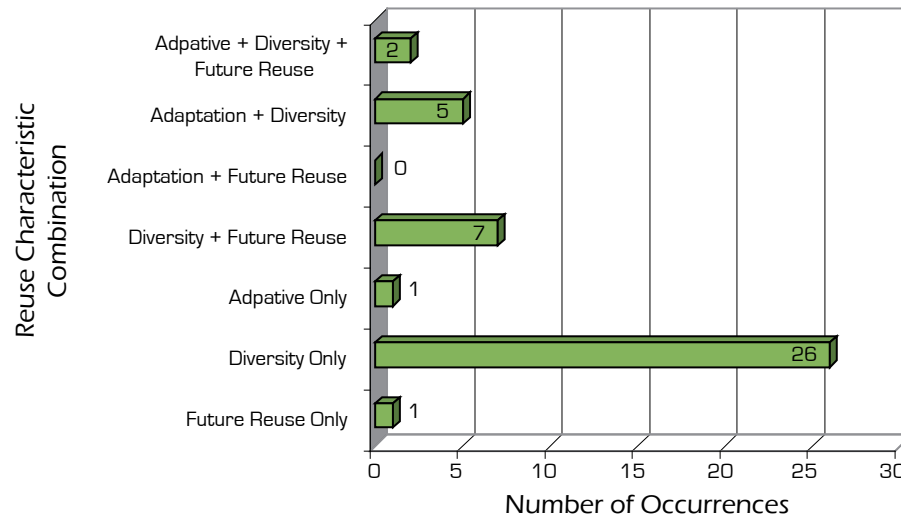


\* See 3G.60 Material Conservation Combinations for further breakdown

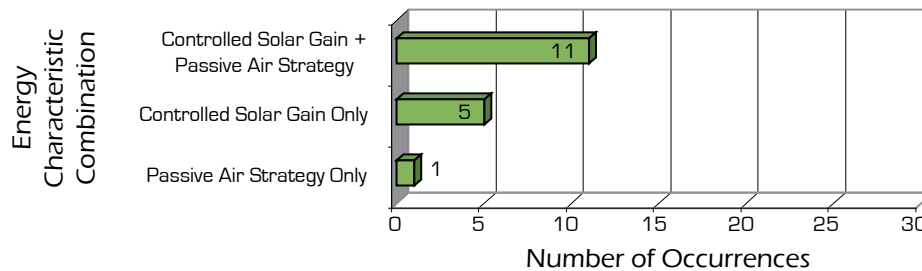
## Conserving Characteristics Combinations 2

Graph 3G.60 - 61

3G.60 - Material Conservation Combinations (Only)



3G.61 - Energy Conservation Combinations (Only)



for a common organizational space and less from a desire for conservationism.

Looking at the energy conservation combinations, there is a high tendency for passive air strategies to occur with controlled solar gain, although the opposite is less true. The relationship between passive air strategies and controlled solar gain is not entirely unexpected as proper control of solar gain is usually required when managing passive air flows: the heating of the air by the sun is what drives the forces to move the air. Furthermore this trend for the deliberate planning of all consecutive characteristics continues to suggest, as mentioned previously, that passive air strategies are the most involved, as compared to other strategies (i.e. daylighting, building reuse and organization). The integration of this characteristic thus implies a high commitment on the part of clients and designers to go beyond superficial nods at 'green' design and pursue a more advanced sustainable project.

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## Endnotes

<sup>1</sup> It should also be noted that this study group does not include all post secondary institutions in Ontario: 14 institutions in the province of Ontario were excluded either because there was not enough available information to properly address the institution's recent construction or the institution was located outside of what was considered Southern Ontario (ie Sudbury or Thunder Bay).

<sup>2</sup> Freda Pagani, "Green Buildings are Still Rare," *The Georgia Straight*, sec. Commentary, 3 November, 2005.

## **Conclusions ::**

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Beginning with a review of the history, development and ongoing proliferation of the atrium, the thesis has examined the modern atrium and outlined its possible 'green' characteristics. The very nature of these characteristics is relevant to the ongoing changes in architectural design and construction, in light of our cultural actions towards sustainability. By bringing together a collection of data through the New Academic Building Survey, the thesis has examined a small portion of the current reality of conservational trends in atria and expressed how they are present in today's academic architecture in Southern Ontario. The results of this undertaking, along with a discussion surrounding the significance of the thesis to future architectural design will follow.

## Summary of Results

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Through the survey of new academic buildings, it was found that 104 buildings were built in post secondary institutions across Southern Ontario between the years of 2000 and 2006. Among the buildings surveyed it was revealed that there were 18 buildings which consider themselves to be materially and/or energy conscious designs and thus conservational to some varying degree. These buildings were termed 'green' and examined separately to contrast with other non-'green' buildings. These 104 buildings, made up of 18 building renovations, 12 building additions and 74 whole buildings, had 63 cases of atria identified, each exemplifying atrium characteristics to some degree (17 of these were from 'green' identified buildings.) It was found that the general occurrence of atria increased with

the size of the building, but no correlation was found with height. The study showed that new autonomous buildings were the most likely to have atria, while building renovations and building additions were less likely respectively.

Also documented was the breakdown of atrium type, atrium location and atrium occurrences of organization and circulation. Even distributions of atria were found between simple and partial atrium type while less were found of the complex type. There was also noted a near equal distribution between centrally and peripherally located atria, with few instances of multiple atria in one building which located atrium in both areas. The most common organizational use for an atrium was as a building hub, followed closely by vertical circulation. Just less than half of the cases in the survey were found to include horizontal circulation and very few maintained none of these organizational uses.

Examining Material (or Reuse) Conservation, the survey showed 8 cases of adaptation, split equally between connective and renovation adaptations. Only two cases of preservation through atria were found. It was clear that a majority of the atria were examples of diverse space, while only a handful demonstrated potential for future reuse. There were no patterns determined when compared with size or height. Breakdowns similar to the overall atria findings were seen when the atrium diversity criteria was divided by atrium type, atrium location and organizational use. Noted deviations from the general survey pattern were seen for the future reuse criteria for the same breakdowns.

Daylighting conservation characteristics showed almost universal use of daylighting (except 2 instances) although there was a much lower occurrence of controlled solar gain (only 16 cases.) A large majority of these controlled solar gain atria occurred in self proclaimed 'green' designated buildings. Daylighting was found to most commonly come from vertical glazing and least frequently from clerestory. The orientation breakdown showed an equal distribution in all compass directions. There were no patterns determined when daylighting conservationism was compared with size or height. Breakdowns similar to the overall atria findings were seen when daylighting was divided into atrium type, atrium location and organizational use, there were however deviations for controlled solar gain for the same breakdowns, with trends deviating from the overall atria patterns.

Instances of passive air strategy were the least of the three areas of conservationism, with only 12 identified cases, all of which were within 'green' tagged buildings. In all except one

instance, the atrium was used for exhaust/cooling passive air strategies. There were no noticeable patterns determined when compared with size or height. This category independently identified itself from the overall atria breakdown. When broken down, it was seen that passive air strategy atria do not occur in partial atria nor are they likely to be located on the perimeter of their building. Additionally, its organizational tendencies showed a consistent inclusion of some form of building organization. These atria were also more likely to act as a building hub and maintain more cases of horizontal circulation than the rest of the atria breakdown patterns in the other areas of conservation.

Collectively it was found that all the characteristics tend to occur consistently over the course of the 7 years surveyed. As a result there appeared no growth in atria based conservationism. Furthermore it was found that the most common combinations of conservational characteristics included all three areas studied. The most common individual occurrence was the diversity of an atrium space.

## Discussion

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In Richard Saxon's book of the early eighties, Atrium Buildings: Development and Design, when referring to the attempt of conservationism in light of the mid 1970s energy crisis, he remarked that the atrium spaces of the 1970s were "visual statements rather than integrated energy systems"<sup>1</sup>. His book went on further to give details on how to better design an atrium to perform with a sense of environmental consciousness.

Despite the high number of atria (61 percent of new buildings) in the thesis' survey, there are not large numbers which have chosen to truly benefit from or capitalize on the potential material or energy reducing qualities of an atrium. Thereby this suggests things have not changed much in light of our current enthusiasm for 'green' design and sustainability. Even though there was almost a universal occurrence of daylighting, the thesis was more interested in this daylighting in conjunction with some form of control. This combination was deemed an especially effective tool for determining sustainable intention, as the overall sporadic glazing orientation suggests that many instances of daylight may in fact have simply fallen where the layout allowed, rather than been strategically placed to get the most light with the least solar gain so as not to overheat in the summer months. Furthermore, at the very least the atrium should be able to bring daylight into the building spaces, yet

the reality of these savings, especially electrical, may not be as significant as would be hoped, as in many public buildings the electrical lighting is left on even during sunny days. Then again the somewhat less tangible improvement of the space for the occupant through psychosomatic channels will occur regardless of the efficacy of natural light infiltration deeper into the building as a means to direct electricity savings; a consideration which surely plays a part in the continued inclusion of 'visual statement' atria.

However, at the same time this study has confirmed the vital role atria have in conservation, as it does occur in buildings which aspire to be environmentally conscious and attempt to work towards sustainability (or 'green' buildings, the term used for these buildings in this study). The development and ongoing learning process is still very much alive and progressing, much in thanks to the work of designers like Richard Saxon and his book on designing atria for energy reduction. This role is evident as seventeen out of eighteen of these specific buildings have both incorporated and made use of their atrium in accomplishing conservational measures, especially in energy savings. In order for a building and its occupants to fully take advantage of an atrium and its possibilities there must be a conscious and deliberate intent in the design and construction of a building to create a sustainably functional atrium. This is evidenced by the huge performance disparity between 'green' buildings and those that simply include an atrium. To that effect, those that try to exemplify material and energy reducing qualities do so very well, while the rest do not. There are no inadvertent conservational or sustainable gestures; these are necessarily more involved and complicated and are successfully implemented only through intentional effort. Consequently, there seems to be a large rift between these two extremes. Looking at the gap between atrium inclusion and a successful atrium in a 'green' sense, one could surmise that the high inclusion of atria in recent developments is a possible reflection of current sustainable thinking trends, but its frequent inefficiency would suggest that the true conservational abilities of an atrium are being over promoted and underutilized. Consequently, this thesis has shown that currently there is little to no growth in material and energy conservation in buildings through their atrium spaces, as trends appear to be consistent from year to year.

## Directions to Designers

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The atrium has strong potential to ensure a building reduces its consumption, improves occupant comfort, and endures through time and changing occupants. Yet it is the process surrounding the atrium's design and completion which will determine its success, as the conserving aspects are not accidental. While the high rate of atrium inclusion is encouraging, small considerations can make a significant difference in the atrium actually reducing material and energy, as opposed to being unresponsive, or worse adding to the resource expenditure. This in turn could substantially reduce the gap observed between the atria that conserve and the ones that do not, simply by cleverly handling a few options differently. It is important to recognize a few simple steps that can significantly improve the atrium's performance and value: a conscious selection of glazing orientation for maximum controlled daylight and minimal unwanted solar gain either through orientation, shading or redirection devices; and the creation of a space appropriate for a variety of uses through the selection of lighting, seating, dimensions, access, and proximity to other high impact program areas. These are aspects easy to accomplish without having to make the atrium a true integrated energy system. As the survey has shown, even though some characteristics are present, such as daylighting, if not properly controlled the energy reduction is significantly held back.

To address the more complicated and involved aspects of the conservational atrium, the key is to begin the design process early and include the atrium as holistically as possible when designing the overall building. This includes integrating both the building with the atrium as well as integrating the architectural design with the performance intentions. Significant aspects such as building orientation and height, local climate and weather patterns, and functional details (such as services distribution, operable vents/glazing, and/or solar chimneys) must be properly thought out to achieve a working atrium. The ever growing 'integrated design process' is one such strategy that is successful for these endeavours. To realize the atrium's potential, the implementation of conservationism must be kept very much in mind and allow the material and energy conscious aspects to dominate the form and design process, rather than the opposite. This too was reflected in the findings of the survey, as those buildings which attempted to conserve, did so in many areas, allowing the building to succeed all round, while those that did not, similarly failed in all areas.

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## Further Areas of Study

As this study is only a glimpse of the atrium designs completed in the past few years, there are many opportunities for further study in immediately related areas. A similar investigative model could be followed in other areas of architecture, for example examining the commercial sector (manufacturing, retail), cultural buildings (performance centres, libraries) and others. The comparison between areas of architectural design could better determine the greatest potential for the use of conservationism through atria, and offer further insight into working cases. Likewise a similar study completed a few years from now in this same area of architecture could continue to study the material and energy conserving trends in atria. As current popularization of 'green' design and sustainable thinking continues to proliferate, these realities may materialize in future completed buildings, and contrast with what has been gathered in the thesis.

In addition there is much potential in examining atrium daylighting, passive air strategies and adaptation, diversity and future reuse independently. Looking at these criteria individually over a wider typological range would provide useful data on successful applications of these strategies in a variety of situations.

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## Endnotes

- <sup>1</sup> Richard Saxon, *Atrium Buildings : Development and Design* (London: The Architectural Press, 1983), 73.

## The Inner 'Green' Space

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Looking back is a good way to go forward. Examining the past reality helps us see the current situation more clearly and accurately, separating truth from hopeful fiction. This examination can also reveal what tendencies and patterns are present in our designs, and highlight areas of poor judgment or of missed potential. In the case of this thesis, the investigation into academic buildings in Southern Ontario was used to identify and reflect on the conservational qualities present or absent in atria, in an attempt to address our progressing goals of sustainable architecture. At the outset, it was noted that our current rate of energy consumption is undesirable for a multitude of reasons, including its inability to be sustained without damage to and adverse affects on our planet and living things. While the thesis has shown that the atria studied have not lived up to their potential in conserving and working to alleviate the burden buildings place on our planet, it has still identified instances of existing atria which do work to conserve both material and energy. It is the knowledge that more can be done which offers hope and the understanding of a few successful examples that hold the key to emulating those instances, so that more effective solutions may be completed in the future.





## **Appendix A :: Building Case Studies**

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The University of Waterloo's new School of Architecture is located in a 100 year old renovated historic building - the former Riverside Silk Mill. Situated along the banks of the Grand River, the former industrial building, built as a steel and wood structure with mill deck flooring, provides wonderful spaces for design studios, labs, and classrooms. It also includes a newly compiled design library, a raked auditorium, a public exhibition gallery, and café. At 85,000 square feet over three storeys, it fits the building programme perfectly. The former industrial building, with its large windows and north facing saw-tooth skylights, provides stimulating spaces for student work areas, presentation spaces and vibrant learning environments.<sup>1</sup>

As part of the renovation, the inclusion of a full height atrium space was carved out at the heart of the building. See fig. A.07 for floor plan. This dramatic feature brings together much of the diverse activity throughout the building while adding an aesthetic architectural volume. By breaching through the building's core, it is able to work horizontally as well as vertically. At the ground level the atrium draws together many elements; the main entry, the formal lecture hall, views toward the river, access to vertical circulation and connections to the public gallery and café. Open circulation on the second floor circles the atrium and allows for connections to the main administrative offices, the Musagetes design library as well as to the photo and computer labs. Interior glazing separates the atrium from the spaces across the third floor. Views from the third floor teaching space and undergraduate design studios look down into this space permitting a bird's eye view of the activity below. Programmatically this is a dominant and vital space.

To complete the success of the design, the atrium works well to bring the outside in. At the front of the atrium space is a glazed wall rising from the ground floor up to the top of the third. Other than being partially interrupted between the ground and second floor, this continuous glazed element allows much westerly light to enter and filter into the rest of the building. Complimented by a series of windows on the opposite side, these allow for scenic river views and the easterly morning light.

A similar aspect of the building, which was part of the original building's design, is the exterior courtyard which the interior atrium mirrors. Unable to connect the program together like its sister interior atrium, the courtyard nevertheless functions



fig. A.01 - Looking across the Grand River at the renovated silk mill that now houses the School of Architecture



fig. A.02 - The atrium space used for a musical performance as part of The Mayor's Celebration of the Arts 2006



fig. A.03 - University assembly which used the school's atrium space as an event hall

similarly in that it can bring light into the design studios, design library and offices which flank it on the third and second floors. Seen through the building long section is the repetition of this 3 storey element – fig. A.08.

The numerous uses of the School of Architecture atrium are countless. From student installations and displays of work to musical performances, formal receptions and everyday gatherings, the atrium is a vital element within the building. On a daily basis, a continuous flow of students and staff move throughout the building using the atrium area for both vertical and horizontal movement. The centralized location allows the atrium to service the majority of programmatic spaces as all major spaces are connected through the circulation of the building which all tie into the atrium.

### Reuse Significance

Renovated at the modest budget of \$100 per square foot, Waterloo's School of Architecture displays an exemplary economy of design.<sup>2</sup> A current trend in architecture is the restoration and reuse of older warehouse and industrial buildings to new uses such as residential condominiums and in this case, a new academic building. The school of architecture has fully exploited the potential of the old silk mill; with the new airy atrium and ample amount and size of windows and skylights, the success of the renovation is easily observed. The School of Architecture was chosen as a case study for its reuse application and for its incorporation of an atrium to an existing building. The building represents the reuse/renovation projects from the universities and colleges study group and coincidentally was the only renovation to have a new atrium space included in this fashion. As mentioned in the section on atrium characteristics (section 1.6), buildings often are renovated or expanded to include a new atrium space; the School of Architecture is a prime example of such a building. As a result of its renovated atrium the school is unique in its elaborate renovation and transformation.

The future reuse potential of the school's atrium can be seen as it is a diverse space continuously being used for many different functions. From student installations and displays of work to musical performances, formal receptions and everyday gatherings, the atrium is a vital element within the building. On a daily basis, a continuous flow of students and staff move throughout the building using the atrium area for both vertical and horizontal movement. The centralized location allows the atrium to service the majority of programmatic spaces as



fig. A.04 - (left) Looking eastward from the second floor.

fig. A.05 - (above) Looking westward towards the main entrance from the second floor

fig. A.06 - (below) Ground floor view of the atrium upon entering the School of Architecture.





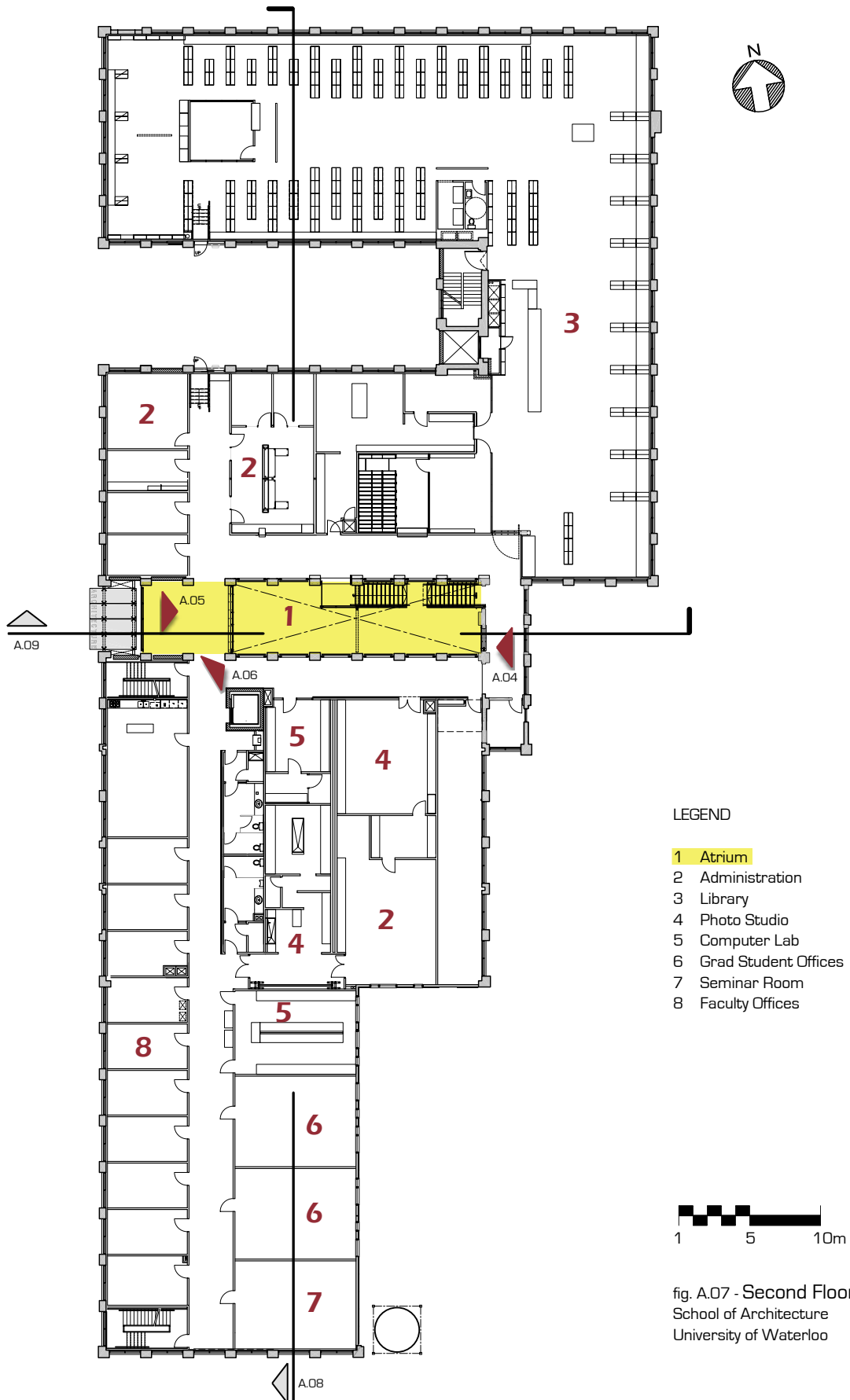


fig. A.07 - Second Floor Plan  
School of Architecture  
University of Waterloo

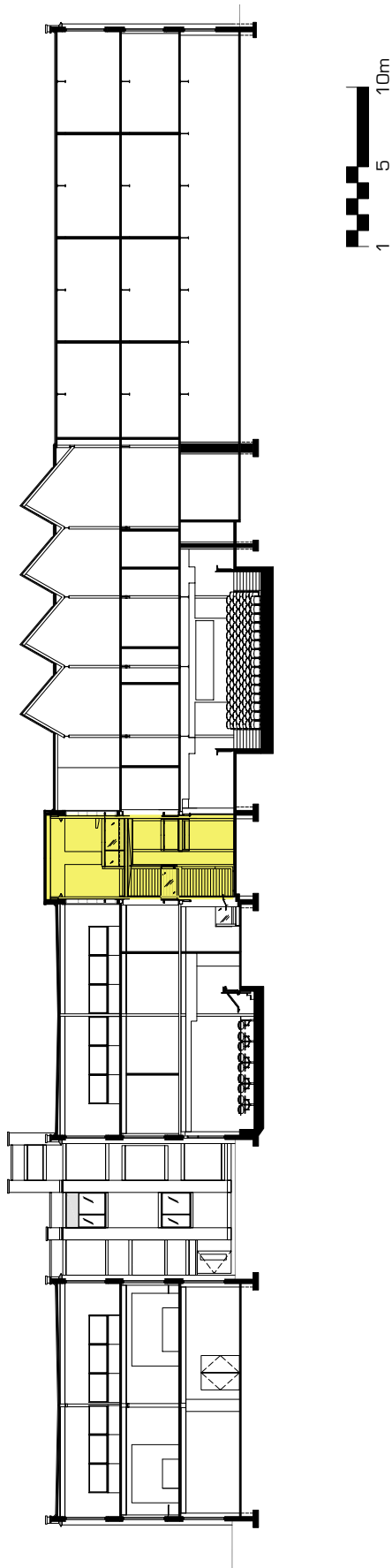


fig. A.08 - Transverse Section  
Looking East  
School of Architecture  
University of Waterloo

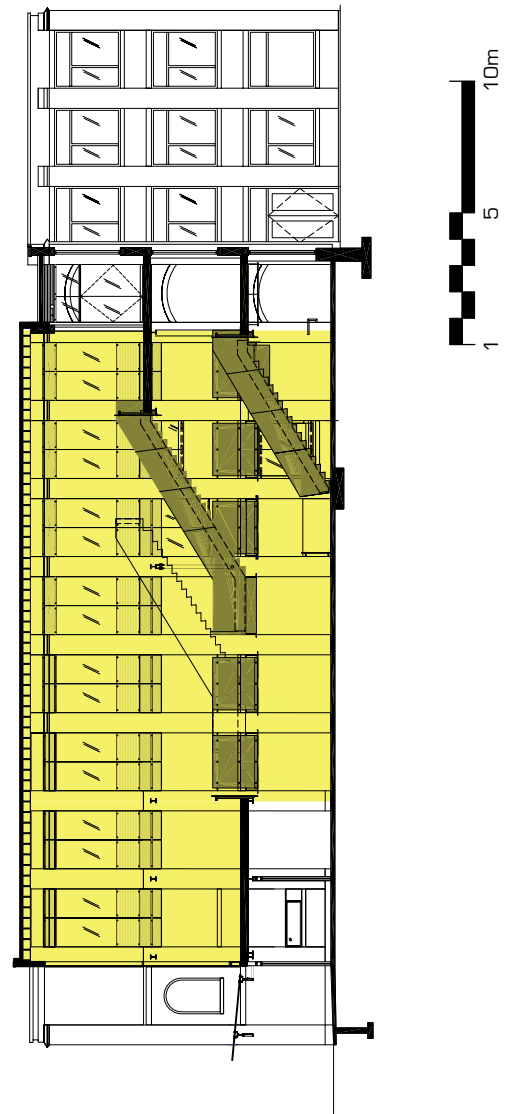


fig. A.09 - Cross Section  
Looking North  
School of Architecture  
University of Waterloo

fig. A.10 - The atrium space used as gallery display space as part of The Mayor's Celebration of the Arts 2006

all major spaces are connected through the circulation of the building which all tie into the atrium. As a result of the many possible uses in the atrium, the space has value for future reuse potential; if the building was used for another purpose the atrium would still be very useful in its many current capacities.





## Centennial College HP Science + Technology Centre

## A.2

The latest addition to Centennial College is its new HP Science and Technology building. The 237,000 square foot complex is home to their Health Sciences programs, along with programs in Business, Engineering Technology and New Media. The building is a four-storey structure composed of two horizontal wings that form a broad V-shape which sits precisely within the contours of the triangular lot. The facility includes a full-service resource centre, six computer labs, 47 specialty labs, classrooms and lecture hall, a cafeteria, administrative offices as well as, meeting, individual and group study spaces.<sup>3</sup>

Centrally located in each wing, light-filled interior hallways run along either sides of an inner atria zone and provide generous circulation spaces culminating in lounges with natural light and views to the site. Once reaching the fourth floor there are a total of five atrium spaces rising amongst the two wings (see fig. A.15 for their location on a floor plan). All rise above the fourth floor ceiling providing a clearstory space that allows the natural light to filter through the atria into the center of each wing of the building. The openness and transparency allows the light, colour and weather of changing seasons to be drawn into the interiors. These rising volumes also allow an extraction of air from the atrium spaces which collect air internally from the rest of the building. See fig. A.16 – A.17 for building sections. Off of these atria hallways are the many classrooms and labs which are used by the various staff and students, many of whom make their way to these rooms by way of the heart of the building.

The heart of the building is where the two wings come together, and is considered 'an indoor Town Square' by the designers. This 'Town Square' creates a social focal point used for gathering and events and is connected to the resource center and cafeteria. The south-east entrance occurs at this point and is articulated as a transparent gateway that draws students into the heart of the space. Amongst this gathering space is a suspended wood-clad volume containing a large raked lecture hall. Beneath it, wide, oversized stairs share the slope of the angled underbelly of the volume and lead to a lounge/café.<sup>4</sup> The wood volume almost appears to float within the building as it separates two rising atria from one another. The first atrium begins at the ground floor south-east entrance and the other beginning on the second floor at the top of the oversized stairs, where the lounge/café sits.

At the base of the other three atria lie the 'iCentre' (information centre) and gathering space, a computer lab as part



fig. A.11 - The southern facade of the HP Science and Technology Centre from the corner of Ellesmere Road and Morningside Avenue in Scarborough, Toronto



fig. A.12 - Looking into the most eastern atrium which contains at its base the Learning Centre's computer lab

of the Learning Resource Centre, and the third a general work/lounge space for students. The most eastern atrium is where lies the Learning Resource Centre computer lab (seen in fig. A.11), and offers a quieter learning environment with a vibrant light filled space. In some ways it creates a very unique space as it is a room with a four storey ceiling. The most northern atrium, houses the iCentre and north entrance. A quite space that is softly lit from above, creates a friendly entrance and illuminates the iCentre desk.

With the multitude of atria throughout the building, there is a varying degree of usage and activity for each. The most activity focuses around the three centrally located atria. Two of these atria have the main entrance gathering and student work space at their base and the third, has the café at the top of the oversized stairs. The activities at the base of these atria fill up with life, making use of the inspiring and light filled space. This vitality rises up through the two central atria and spills onto each floor as there are benches for gathering/resting at the atria on each level. At the top floor these atria open up (see fig. A.14 for panoramic image) and have a further public space that is occasionally used by students.

In addition, the building uses a combination of entrances to address its occupants and visitors. Systems of movement through the building are activated from three sides: the (main) south-east entrance at ground level accommodates students arriving via public transit; the second level entrance provides direct access from the visitor parking lot on the north; and the fourth level entrance is linked directly to a parking lot on the tableland to the north-east via a sculpted pedestrian bridge.<sup>5</sup>

Pragmatically the HP Centre uses a variety of passive means to achieve sustainable objectives for the building's operation. The design intent is to reduce the building's operating costs by using design elements to supplement the mechanical systems of the building. Using the atrium spaces the building passively cools, ventilates and lights much of the building along with maintaining high energy efficiency with exposed concrete on the interior providing a high thermal mass.

The HP Centre's ventilation is a hybrid natural ventilation system. The building is designed around interconnecting atria which provide visual connection to all floors as well as a source of ventilating air. Natural cross ventilation is achieved by transferring air from operable windows on the perimeter of the building, through the forty foot deep academic space and into the atria where air is relieved at the top of the building (stack effect). The operable windows will decrease the mechanical cooling requirements during the shoulder seasons (spring and



fig. A.13 - (left) Looking in the central atrium at the student work space and the suspended wood clad lecture hall volume to the right

fig. A.14 - (above) Looking up the atrium at the top of the oversized stairs

fig. A.15 - (below) Looking across the tops of the central atria from the top floor





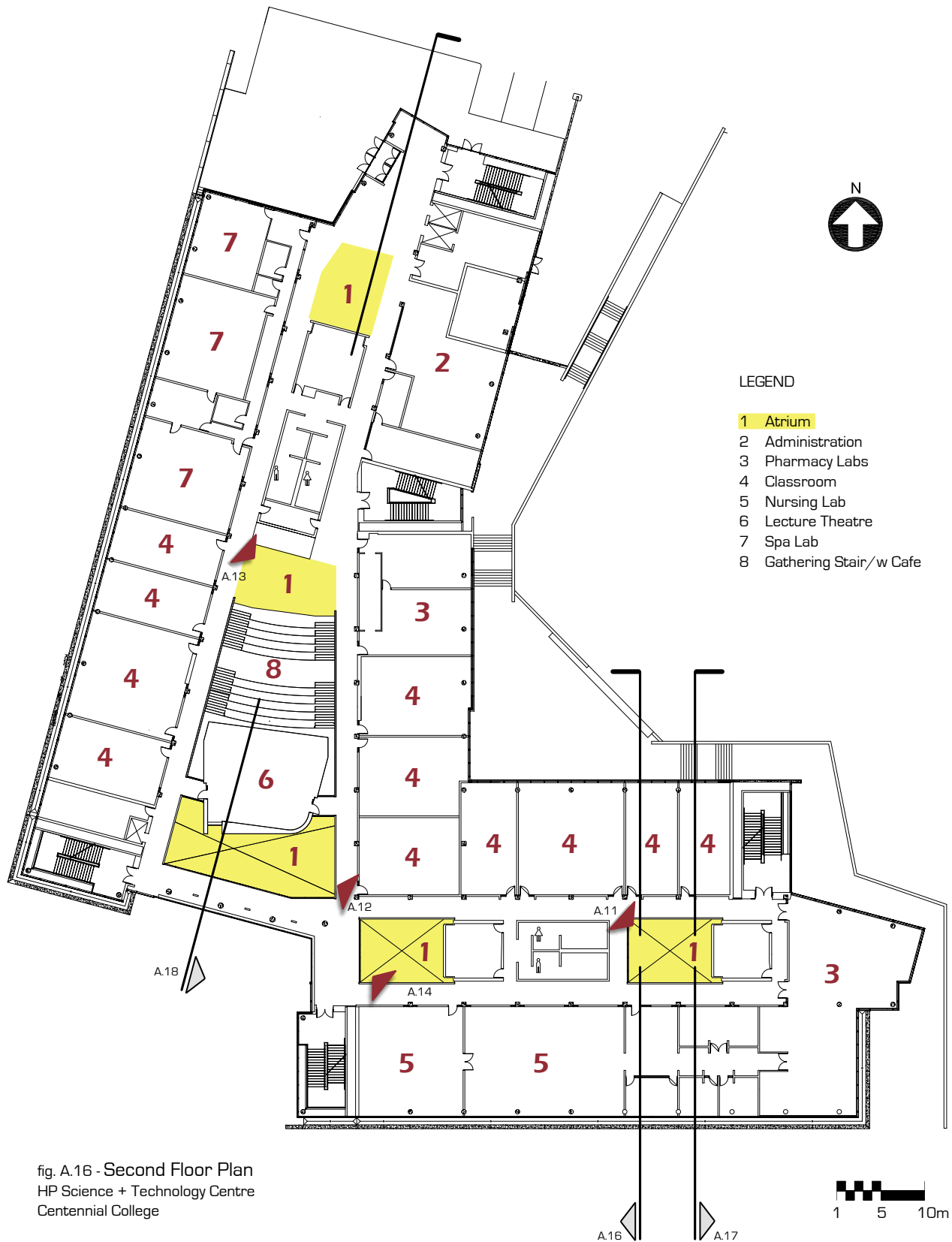


fig. A.16 - Second Floor Plan  
HP Science + Technology Centre  
Centennial College

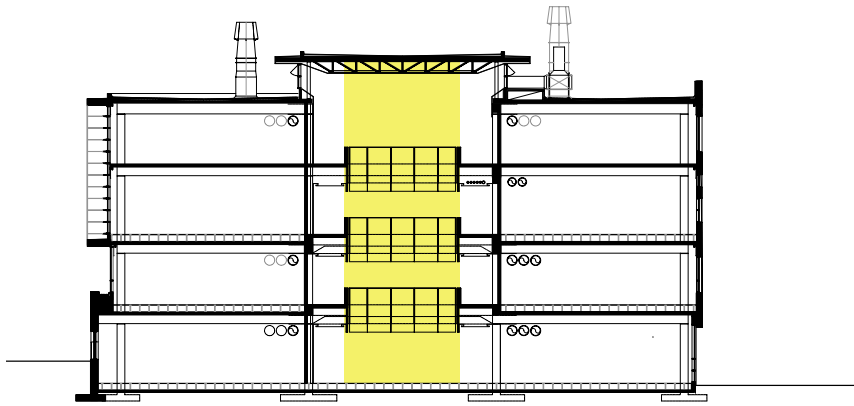


fig. A.17 - Cross Section  
East Wing - Looking West  
HP Science + Technology Centre  
Centennial College

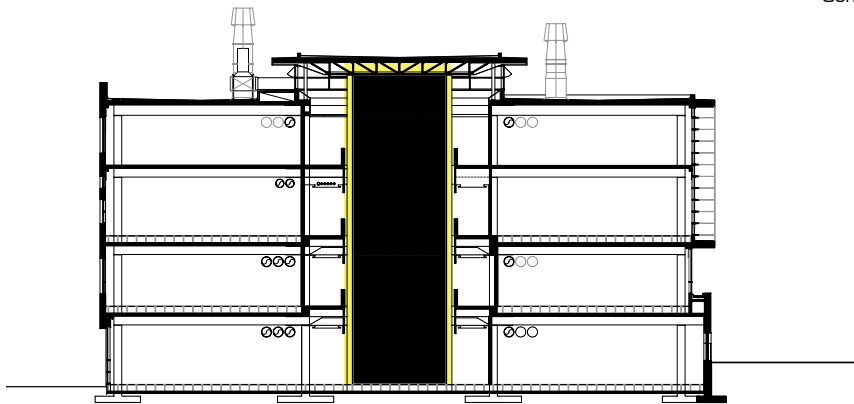


fig. A.18 - Cross Section  
East Wing - Looking East  
HP Science + Technology Centre  
Centennial College

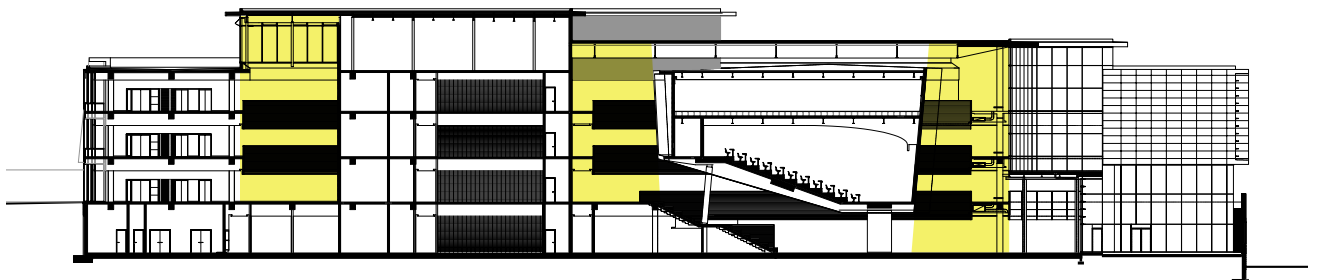


fig. A.19 - Transverse Section  
West Wing - Looking East  
HP Science + Technology Centre  
Centennial College



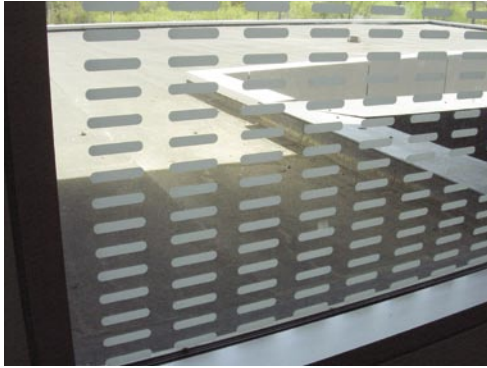


fig. A.20 - Close up of fritted glass pattern used on the south facing facade



fig. A.21 - Atrium clerestory glazing with exhaust vent and roof overhang behind

autumn).<sup>6</sup> Further mechanical cooling tower and chiller system are placed on the roof, with compartment units centrally located on each floor for ventilation and air distribution through underfloor plenum, and fan units severing the perimeter zones. A raised floor system is used as the underfloor air plenum which distributes air directly to the occupants, and allows individual temperature control. This delivery system is used in combination with the natural ventilation to reduce the number of moving parts in the mechanical system.<sup>7</sup>

### Daylighting Design Significance

The HP Science and Technology Centre was chosen for its abundant use of atria across a large sum of the building. No other building within the university and college survey had such a recurrent use of the atrium element. Five full height atria were used in total, integrated repetitiously throughout both wings of the building, and occurring as both part of the public and programmatic space.

All atria rise above the fourth floor ceiling providing a clearstory space that allows natural light to filter through the atria into the center of each wing of the building. Centrally located in each wing, light-filled interior hallways run along either sides of an inner atria zone making use of the generous amounts of natural light. The openness and transparency allows the light, colour and weather of changing seasons to be drawn into the interiors and reduce the need for artificial lighting for most of the daytime. The infusion of natural daylight is a large part of the building's design to provide high energy efficiency which substantially reduces operating and maintenance costs.

To control the daylighting the HP Centre has employed a few techniques to diffuse the daylight and reduce the solar gain. Across the front of the building, which mainly faces south, the control of light and solar gain is most important. Fritted glass has been used on the vertical glazing to help diffuse the direct light. In addition, the incorporation of large overhangs as part of the façade design, help control solar gain from the high summer sun. Similar overhangs have also been designed over the clerestory glazing at each of the full height atria. These overhangs reduce the amount of direct light coming into the building, creating soft diffused light for the inner building hallways and rooms.

As a further means of energy efficiency the HP Centre employs a large amount of exposed concrete on the interior to provide a high thermal mass to exceed the ASHRAE 90.1 standard for energy efficiency by 40%.<sup>8</sup> Thereby in the winter

the solar gain which comes from the lower winter sun enters through the south façade (no longer blocked by the overhang) and stores its heat in the exposed concrete floors and walls to help reduce the amount of heating required for the building.

The HP Centre is a very successful building both pragmatically and aesthetically. With its generous amounts of open space, the building was able to be completed under an extremely restricted budget. The design fulfills the program requirements along with incorporating the atria to form emotive spaces, maximize natural light and achieve hybrid ventilation. The design creates seamless integrations of low-tech strategies such as building orientation with user needs, and eco-tech strategies such as the atria daylighting and air movement system. This integration provides high energy efficiency which substantially reduces operating and maintenance costs.<sup>9</sup>





## York University Computer Science Building

## A.3

The York University Computer Science Building is a 102,250 square foot, four level building combining undergraduate lecture halls and computer labs, found primarily on the ground and sub-grade levels, with graduate and faculty offices on the upper floors all coupled with two large atria spaces. As part of the main York University campus in North York, Toronto, the building houses space for the computer science and computer engineering programs which run out of the Faculty of Science and Engineering. Broken down elementarily, the building's composure falls into three main elements: the large lecture hall, the two atria, and offices/labs which surround the atria. The broad circulation spaces between the programmatic volumes, run in grid patterns east to west and north to south, and relate to the overall circulation of the surrounding campus.

Right from the conception of design for this building, the intent was to be mindful of the environmental impact the building would have both during construction and during its lifetime operation. Therefore the programmatic elements are located to best suit the sustainable objectives and site requirements. For instance, the main entry opens up to the south exposure and Campus Walk, giving a visual welcome to the campus and allowing indirect light to enter through louvers and canopies. On the opposite side of the building, heat generating computer labs have been located along the north façade to reduce the heating loads required during the winter. Likewise, in the summer the northern exposure also has low cooling requirements. The interior spaces are organized around the atriums to allow for perimeter services, natural day lighting, staged air zones, natural ventilation and passive heating/cooling.

The two atria each take a separate form and approach toward their implementation into the design. The first, more formal and traditional space is the east atrium, located in the north east quarter of the building (see floor plan – fig. A.28). Its almost square plan begins on the basement level and reaches up just past the third floor above ground for a total of four and a half storeys. Along with some adjoining hallways this atrium is surrounded by offices, allowing the natural daylight to filter into the working spaces. At the base is an interior garden with a lounge/meeting place off to the one side. The east atrium is intended to serve a portion (surrounding offices) of the building rather than the whole building.



fig. A.22 - Looking at the south facade of the York Computer Science Building from the York University Campus Walk

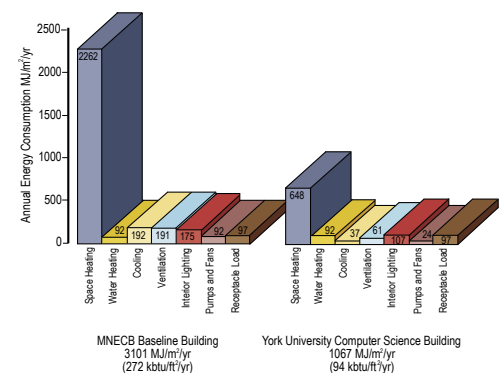


fig. A.23 - Energy assessment used in the Green Building Challenge for the York Computer Science Building against an equivalent standard building

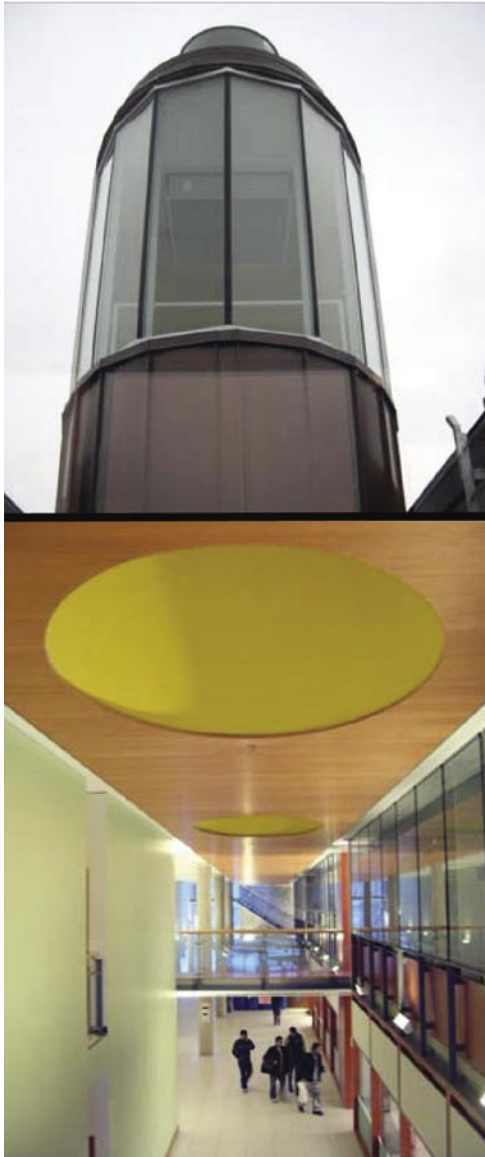


fig. A.24 - (above) Composite image of the exterior of the solar chimney

fig. A.25 - (below) The west atrium ceiling opening for the solar chimney

The second atrium is the west atrium, a less formal atria element, which doubles as an axial hallway and runs the length of the building, from north to south. Starting on the main floor and rising to the top of the second level, where above this section, a roof begins as part of the third floor walk out roof. As a result, this atrium space does not rise above the overall height of the third floor, but instead makes use of multiple thermal chimneys with wind scoops/extractors to reach the full overall building height. See image compilation fig. A.23 + A.24. Along the west side of the west atrium further visual links are created by the glazed partitions of the adjoining computer labs, which run along that side. Although, unlike the east atrium, less light is brought into the west atrium due to fewer skylights, thereby giving each a distinguishing atmosphere from one another. Also within this atrium on the second floor is an open circulation bridge which connects the second floor on either side of the west atrium.

Beyond the west atrium, at the south end of the building is a unique space which is found under the sloped plane of the second storey of the main lecture hall. As part of the main entry off of the Campus Walk, this informal gathering space contains a café with seating and offers access to the large lecture hall above it and the smaller lecture halls below it. This space acts as a hub for the building and dissolves into the west atrium space and onto the rest of the building.

Due to the mechanical system having two distinct modes (summer/winter and spring/fall) the building can function extremely efficiently year round, especially in the shoulder seasons (spring/fall) when the building operates primarily naturally and cost free. In a temperate climate a building could operate in this manner year round. Two dominant elements which help achieve this are, the building's capability to harness its thermal mass and its ability to take advantage of thermal stacking.<sup>10</sup> A further contribution to its efficiency is the ability of the air handling units (AHU) and fancoil units to be used to assist air movement without needing to condition the air.

Additionally, in order to reduce the amount of energy consumed while using a passive design, a broader range of indoor air temperature and humidity was intended to be tolerated. The temperatures in the lecture theatres and atria will be maintained between 18°C and 26°C, in the classrooms and offices it will be between 20°C and 23°C. The effect is the temperature gradually steps from the outdoor temperature to the public spaces temperature and then to the classroom/office temperature. This also results in a greater efficiency as the AHUs are 30% smaller than the size of those in a conventional



fig. A.26 - (left) Looking down into the east atrium from the third floor.



fig. A.27 - (above) Image of the south end of the west atrium.

fig. A.28 - (below) Looking north down the west atrium.



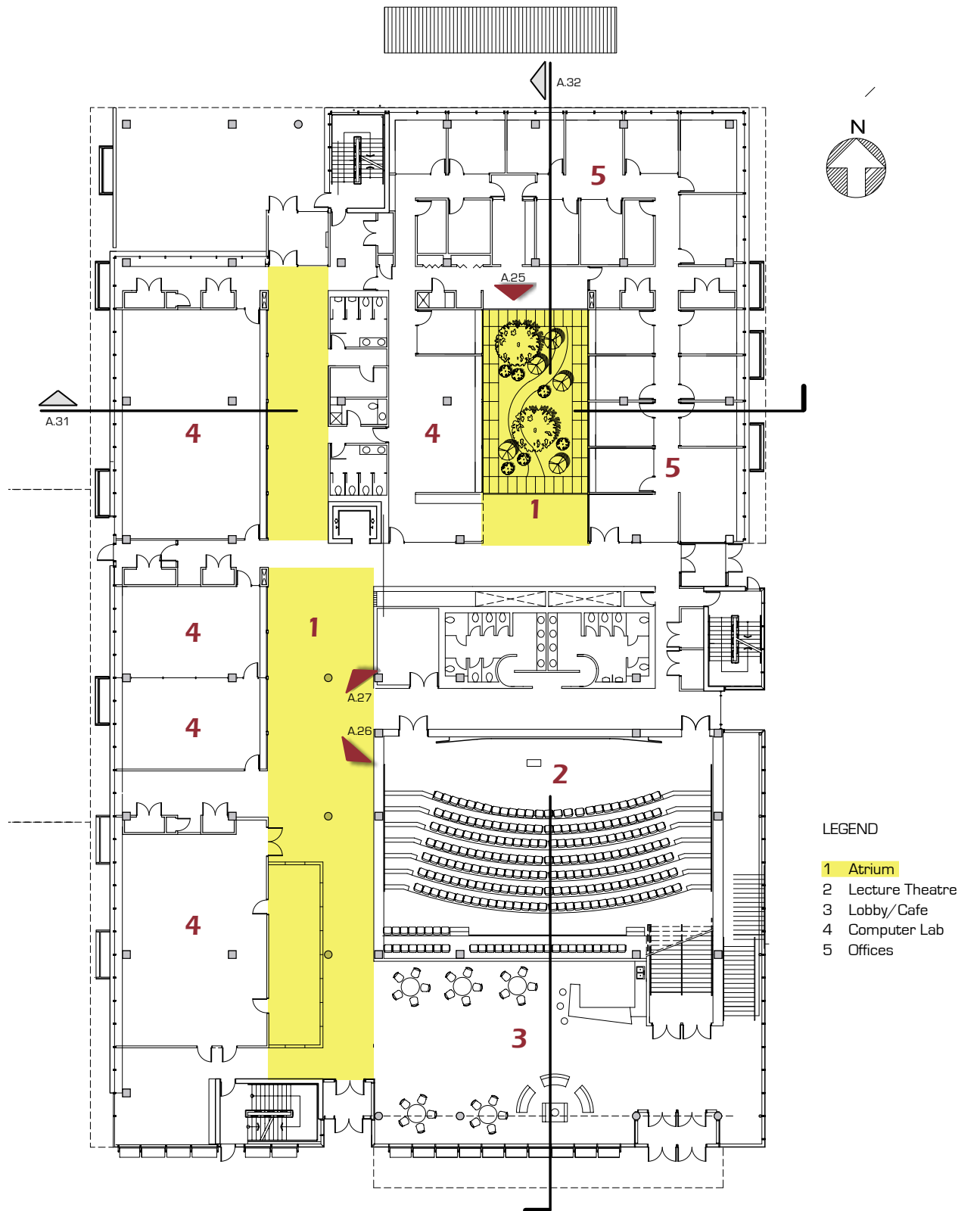


fig. A.29 - Ground Floor Plan  
Computer Science Building  
York University



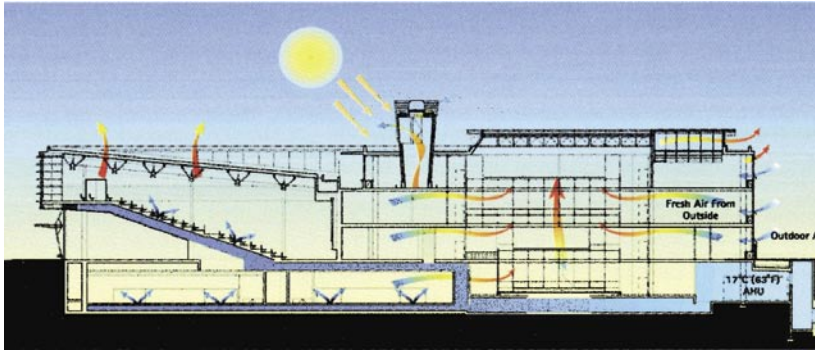


fig. A.30 - Schematic Section  
Showing spring/fall condition:  
operable windows and stack dampers  
are used for natural ventilation, drawn in by  
the stack effect created in the atria.

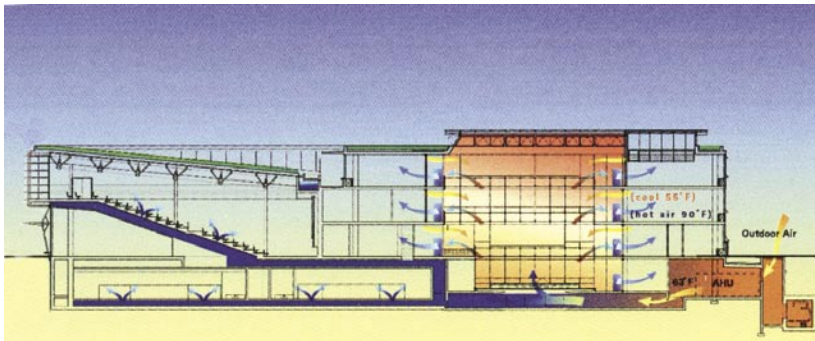


fig. A.31 - Schematic Section  
Showing winter/summer condition:  
office windows and stack dampers are  
closed, and outdoor air mixes in the  
atria with return air from theatres and  
classrooms.

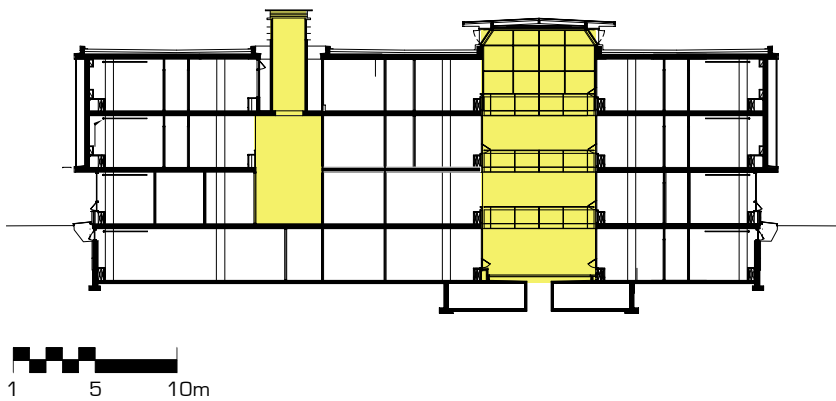


fig. A.32 - Cross Section  
Looking North  
Computer Science Building  
York University

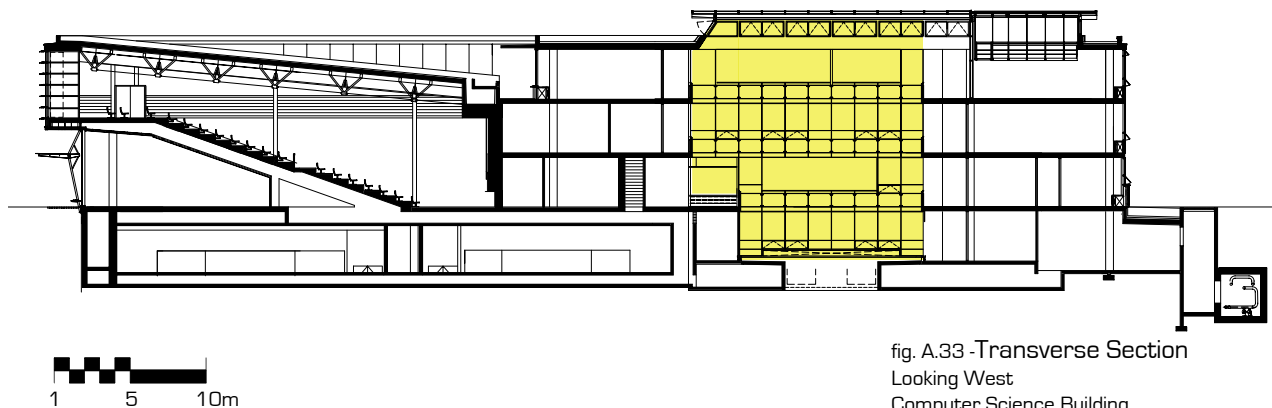


fig. A.33 - Transverse Section  
Looking West  
Computer Science Building  
York University



fig. A.34 - (above) Close up of the opening in the wall to allow air passage



fig. A.35 - (below) Image of the vented wall partition above a hallway door

building, since less conditioning is required. The design of the York Computer Science building also gives occupants the ability to control their environment by using operable windows. This opportunity has the potential to reduce energy, while accepting a broader range of temperatures and humidity conditions. The social cost of this building in regards to user comfort is minimal. In many ways, user comfort is enhanced due to personal control over lighting, operable windows and air diffusers.

This high tech building employs a low-tech/echo-tech approach that is primarily passive in nature to exceed the standard model for energy consumption by 40%, when compared with an equivalent standard building as part of the Green Building Challenge (see comparison graph, fig. A.22). This significant accomplishment is achieved through many different design measures, all of which build upon one another to produce a highly efficient building.

### Air Design Significance

Utilizing natural ventilation, the Computer Science building has no traditional duct work as the atrium spaces help to capture heat stratification opportunities – a fundamental aspect of the ventilation strategy. Stratification is created differently in both atria. In the east atrium, the space rises four and a half storeys to formulate the temperature differential, while the west atrium is two storeys high with the addition of two solar chimneys atop the atrium, using the combination of the atrium height and added solar gain to create the temperature differential.

Given the relatively deep floor plate, atria are used to enhance natural ventilation and also provide day lighting to the space in conjuncture with operable windows and high-level stack ventilation. As well, underfloor air delivery in the lecture theatres promotes stratification, which reduces the cooling loads while enhancing natural ventilation through buoyancy effects (stack effect). To ensure the success of the passive air movement strategies, the designers consulted RWDI (refer to Appendix D), a wind and air engineering consultant specialist, during the design of this building to quantify the design intentions about air movement.

The building's ventilation operates in two distinct modes. See fig. A.29 + A.30. In the *Spring/Fall* mode the building opens up and air flows through operable windows into the classrooms and offices passively. The air then migrates into the corridors which are interconnected with the atria. The air transferred to the atria is released through high level openings. The atria also naturally draws cool air through the underground plenum to

displace the exhausting air leaving the atrium. Wind direction sensors control these openings in order to eliminate downdrafts. To extend the range of outdoor temperatures for which natural ventilation can be used smoke exhaust fans can be run at half speed in order to assist in ventilating the space.<sup>11</sup>

In *Summer/Winter* mode the building is essentially “closed up” as mechanical systems are used to provide heating/cooling to the space. One air handler delivers fresh, tempered air to the atria space. Small local fancoil units on the perimeter of the spaces take the air from the atria, further condition it and deliver it to the occupied space. A second air handling unit serves the two basement lecture theatres and the large theatre via an underfloor supply system. The air is then partially released back into the atria, which serves as a mixing plenum for the fresh air delivered by the air handling unit and the return air from the classrooms, offices and theatres. The remainder of the air delivered by the fancoils is exhausted through the roof. The atria are indirectly conditioned by transferred air from the occupied space.<sup>12</sup>

To help transfer the air between occupied office and lab spaces, while maintaining a certain level of privacy, inventive partitions were used. By forcing the air to jog through the partition, noise would be partially dampened to address acoustical issues. See fig. A.35 for an example of the wall section showing the setup for this air penetrating partition.

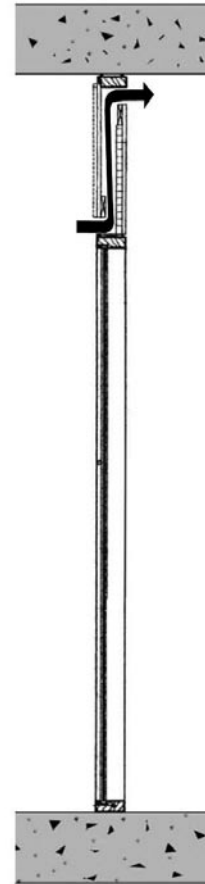


fig. A.36 - Wall section drawing showing the air passage design to allow filtrating air to penetrate through.

Based on the three case studies in the previous sections some basic statistics are compiled for comparison in Table A.1. Each case study was chosen for its distinct use of atria within its building. The comparison shows how the three projects are very distinct from one another, yet each offers an exemplary illustration of the three areas of atrium conservation used in this thesis assessment. These examples were extracted for further examination, providing insight into reuse, daylighting and air movement within the building and its relation to the atrium. Whether it was a renovation and conversion with a new atrium as part of the redesigned School of Architecture or the light filled and extravagant five atria HP Science and Technology Centre or an innovative dual atria system for air movement such as the York Computer Science building, each building presents an unique point of view in the use of atrium for conservational design.

To compliment the comparison, on site visit were taken to each of the three buildings to make observations and take readings within the atrium spaces. For on-site analysis, quantitative measurements were taken with two pieces of equipment. The Tel-Tru, Tel-Fast non-contact thermometer was used for obtaining surface temperatures. Its ability to read surface temperatures above and beyond the reach of the examiner was very useful and allowed for readings of ceilings, solar chimneys and atrium vents. The second piece of equipment was the 746 Environmental Monitor made by Elsec, which can measure UV, visible light, temperature and humidity. Only the air temperature measurements within the various spaces of each building were recorded. It should be noted that the non-contact thermometer, would consistently show readings 1.5 to 2°C warmer than the Elsec thermometer.

### Observations - School of Architecture

An understanding of the interior workings of the School of Architecture Building was conducted by measuring surface temperatures. The main goal of these measurements was to identify any air stratification in the atrium, as well as obtain an idea of the overall building environment.

Although no atrium air movement is intended for within the School of Architecture, measurements were taken to see what kind of stratification could be found. Having taken measurements on days as cold as 6°C and as hot as 26°C (the same temperature range as the other case studies), it was found



Table A.1 - Case Study Comparison Chart

York Computer Science		School of Architecture		HP Science + Technology	
City	Toronto (North York)	Cambridge	Toronto (Scarborough)		
Geographical Location	Southern Ontario Canada	Southern Ontario Canada	Southern Ontario Canada		
Year of Completion	2001	2003	2003		
Architect	Busby + Associates <i>with</i> Architects Alliance	Stanley Saitowitz Office <i>with</i> Levitt Goodman Architects	Kuwabara Payne McKenna Blumberg <i>with</i> Stone Kohn McQuire Vogt Architects		
Mechanical Engineer Consultant	Keen Engineering Co. Ltd. <sup>1</sup>	Keen Engineering Co. Ltd. <sup>1</sup>	Keen Engineering Co. Ltd. <sup>1</sup>		
Area (Gross)	102,250 sqft	85,000 sqft	237,350 sqft		
Construction Cost Cost/sq.ft.	\$16.8 million \$164/sq.ft.	\$8.5 million (Renovation) \$100/sqft	\$43 million \$181/sqft		
Daylighting	Skylight + Clerestory Sun shades and overhangs	East+ West vertical glazing No controls	Clerestory + West vertical glazing Fritted glass and overhangs		
Air Handling Setup	Hybrid - Passive/Mechanical Shoulder Seasons	Mechanical with Operable Windows <sup>2</sup>	Hybrid - Passive/Mechanical Shoulder Seasons		
Reuse	None	Adaptive reuse of old factory building Versatile atrium space	Versatile atrium space		
Number of Atria	2	1	5		
Atrium Area (Footprint)	3,905 sqft	1,175 sqft	4,208 sqft		
Building Footprint Percent	13.5%	4.2%	6.3%		
Atrium Area (negative space)	6,390 sqft	2,280 sqft	11,156 sqft		
Atrium Area (all floors)	10,295 sqft	3,455 sqft	15,364 sqft		
Atrium Percent	10% of building	4.2% of building	6.5% of building		
Floor Area to Atrium Ratio	10 : 1	24 : 1	16 : 1		
Atrium Use	East atrium used as a garden. West atrium space as part of the cross building hallway. Both used for air movement including wind cowl as part of the west atrium	Full height atrium in the heart of the building tying the programs of the building together used as circulation and gathering/reception space	All five atria throughout the building are used as part of the air movement system. Each supports a distinct program spaces on their ground floor: computer lab, lounge, a café and gathering spaces		
Site Observations					
Atrium Stratification					
Cooler (<17 °C)	2°C (east + west)	1°C	2°C (consistent throughout)		
Warmer (>17 °C)	2°C (east), 3°C (west)	2°C	2°C (consistent throughout)		

<sup>1</sup> Keen no longer exists as they merged with Stantec as of October 3, 2005<sup>2</sup> Included in design but occupants can no longer use

that a 1°C stratification was found during most of the tests, and only on the hotter days was a 2°C stratification found. It was further noted that there are no vents for any of the air to move out of at the top, nor any mechanical ducts found within the atrium, only ones that lead up to the side of the atrium space.

#### Observations - HP Science and Technology Centre

Several site visits were conducted and measurements taken on different days, each with different outdoor weather conditions to help understand the interior workings of the HP Science and Technology Centre. The main goal of these visits was to identify any air stratification in the atria, as well as obtain an idea of the overall building environment. Having visited the building on several occasions, with varying degrees of occupancy, a further understanding of how the occupants used the building and their response to the atrium spaces was also noted.

The HP Science and Technology building was visited on days as cold as 3°C and as warm as 27°C in an attempt to cover the shoulder seasons' temperatures which would make use of passive air handling and activate the atrium spaces. Atrium vents were rarely observed to be open, at best it seemed they were used at temperatures over 20°C. Although other openings at the top of the atrium were always open and were connected to exterior solar chimneys. During the colder days, outdoor temperature of 17°C or less, the average ground floor surface temperatures were found to be 21°C at the base of all atria. The building was also found to be consistent on the top floor as all fourth floor surface temperatures were 22°C and 23°C at the upper most part of the wall near the ceiling. Thereby there was a 2°C stratification found in the atria. During the warmer visits, the ground floor surface temperature was from 23 - 24°C. The surface temperature observed on the top floor was found to be 26°C. Therefore there was a 2°C stratification found in the atria during the warmer days.

#### Observations - York Computer Science Building

Several site visits were conducted on different days, each with different outdoor weather conditions to help understand the interior workings of the Computer Science Building. The main goal of these visits was to identify any air stratification in the atria, as well as obtain an idea of the overall building environment. Beyond any technical information gathered, these visits also were to acquire an understanding of how the occupants used the building and how they respond to the atrium spaces.

The York Computer Science building was visited on days as cold as 4°C and as hot as 26°C in an attempt to cover the shoulder seasons' temperature which would make use of passive air handling and activate the atrium spaces. Generally it was found that the greater the outdoor temperature, the greater the stratification of temperature found within the building. Atrium vents were observed to be open between temperatures of 10°C and 26°C, whereas the occasional operable office window could usually be seen open. During the colder days, outdoor temperature of 17°C or less, the ground floor surface temperatures were found to be 19 - 21°C – colder in the west atrium, warmer in the east atrium. While the upper floor of the west atrium (second floor), maintained surface temperatures of 20°C and 21°C within the solar chimney, the east atrium, with its warmer ground floor surface temperatures, had third floor temperatures of 22°C and sometimes 23°C. Therefore there was a 2°C stratification found in the atria.

During visits on warmer days, the ground floor surface temperatures were from 23 - 24°C. Again, the warmer temperature was found in the east atrium. In the west hallway atrium, the upper level surface temperatures were usually 24°C and solar chimney temperatures were usually 26°C but was once recorded as high as 30°C. Within the east atrium, the ceiling surface temperature observed on the top floor was found to be as warm as 26°C. As a result, even without measuring instruments, it was noticeably warmer in the upper floors on the higher temperature days. Thereby there was a 2 - 3°C stratification found in the atria during the warmer days.

## Endnotes

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<sup>1</sup> University of Waterloo School of Architecture, "A New Home for the School," <http://www.architecture.uwaterloo.ca/cambridge/index.html> (21 July 2006)

<sup>2</sup> Levitt Goodman Architects, "Projects - Educational - School of Architecture U of W," <http://levittgoodmanarchitects.com/project?p=uwsa&c1=educational&c2=None> (21 July 2006).

<sup>3</sup> Read Jones Christoffersen, "What we do - HP Centennial College, Science and Technology Centre," <http://www.rjc.ca/cms/page1653.cfm> (27 June 2006).

- <sup>4</sup> KPMB Architects, "Projects - Centennial HP Science and Technology Centre," <http://www.kpmbarchitects.com/index.asp?navid=30&fid1=48&fid2=10&fid3=32&minyearx=&maxyearx=> (27 June 2006).
- <sup>5</sup> Weekly Dose of Architecture, "Centennial HP Science and Technology Centre," <http://www.archidose.org/Feb06/022706.html> (10 February 2006).
- <sup>6</sup> KPMB Architects, Centennial College Science and Technology Centre - Project Brief Press Release, 4 .
- <sup>7</sup> Ibid, 5.
- <sup>8</sup> Weekly Dose of Architecture, *Centennial HP Science and Technology Centre*
- <sup>9</sup> KPMB Architects, *Centennial College Science and Technology Centre - Project Brief Press Release*, 1
- <sup>10</sup> John McMinn, "Sustained Discussion," *Canadian Architect* 46, no. 1 (JAN, 2001), 17.
- <sup>11</sup> David R. Macaulay and Jason F. McLennan, *The Ecological Engineer* (Kansas, MO: Ecotone Publishing, 2006), 151-160.
- <sup>12</sup> *ibid.*, 158

## **Appendix B :: Academic Building Catalogue**

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## Police and Public Safety Institute

**B.001**

Algonquin College  
Ottawa, Ontario

93,885 sqft

3 storey building with classrooms,  
training classrooms, training gyms  
and offices

Small 2 storey basic atrium at the  
main entrance, but does not go  
the full height of the building

**Completed 2000**

**Griffiths Rankin Cook Architects**





**B.002**

## **School of Advanced Technology**

116,000 sqft

Algonquin College  
Ottawa, Ontario

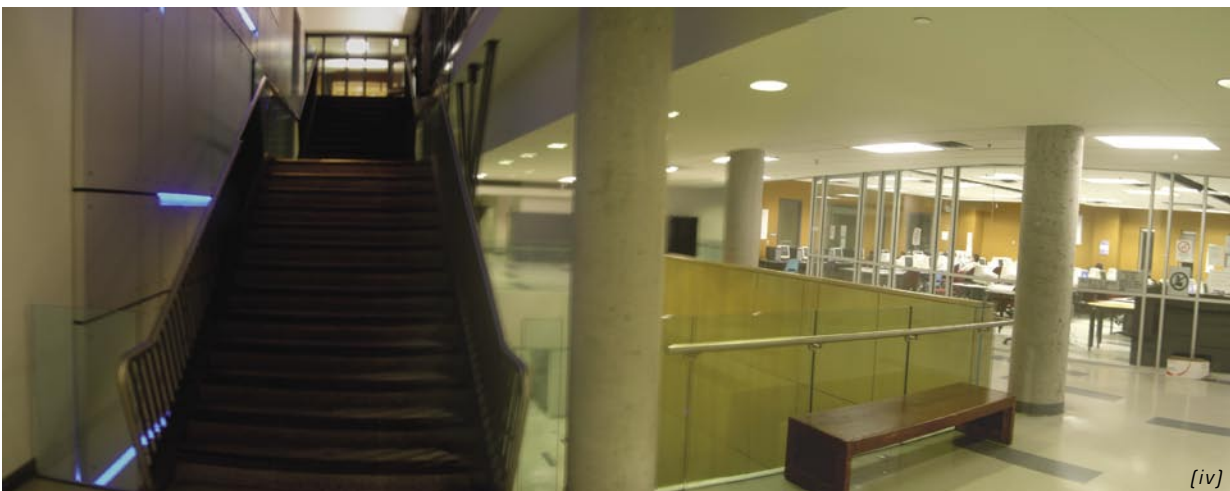
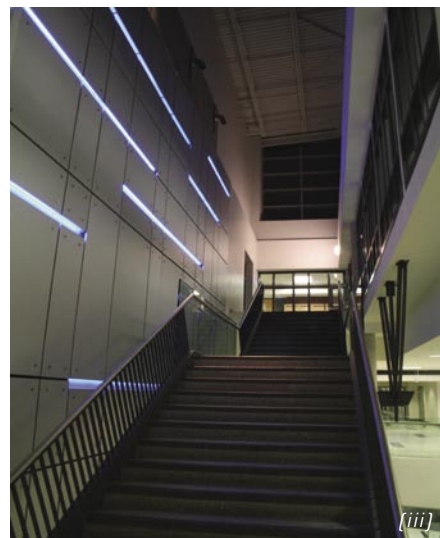


3 storey building with theory classrooms, computer labs, electronic labs, a 225-seat amphitheatre and staff offices.

Large full height circulation atrium space at the east end of the building, mainly used as vertical circulation and gathering space which also connects to the main entrance

**Completed 2002**

**Griffiths Rankin Cook Architects**



## Transportation Technology Centre

**B.003**

Algonquin College  
Ottawa, Ontario

32,000 sqft

Single storey building to house labs, classrooms, 18 repair bays and a body shop area for transportation trades

No atrium used in design

**Completed 2004**

**Griffiths Rankin Cook Architects**



## Scotia Bank Hall

**B.004**

Brock University  
St. Catharines, Ontario

29,496 sqft

3 storey addition used for computer commons and offices

No atrium used in design.

**Completed 2001**

**Moriyama + Teshima Architects**



## B.005

80,083 sqft

## South Block

Brock University  
St. Catharines, Ontario

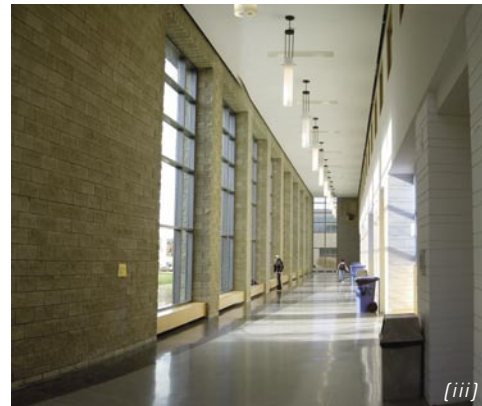


3 storey building with multiple lecture halls, a food court and offices

2 1/2 storey basic atrium space where the South D building merges with the Walker Athletic Building, used as a food court. Also a 2 storey open space hallway along the front façade



**Completed 2001**  
**Moriyama + Teshima Architects**





## East Academic

**B.006**

Brock University  
St. Catharines, Ontario

7,262 sqft

Single storey building for  
classrooms, labs and offices

No atrium used in design.

**Completed 2003**  
**William Haas Consultants Inc**



**B.007**

90,811 sqft

## **University Plaza Building**

Brock University  
St. Catharines, Ontario

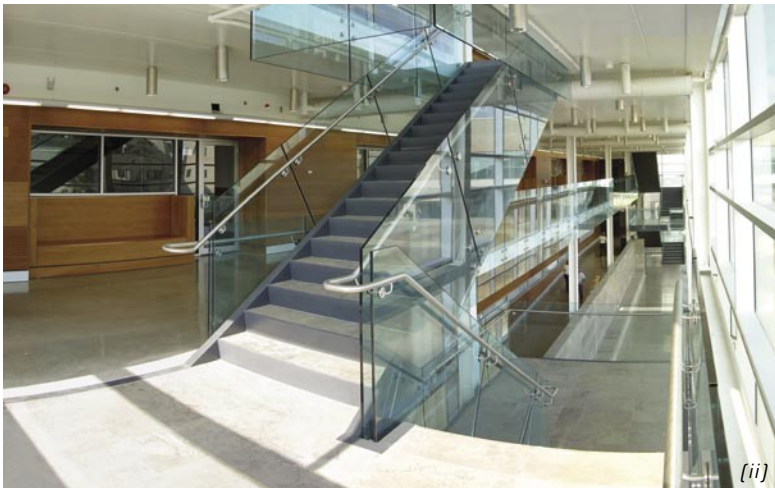


6 storey building consisting of commercial space for university amenities with labs and offices above

4 story north facing atrium which incorporates both vertical and horizontal circulation, and intended for basic air movement strategies

**Completed 2006**

**Brian MacKay-Lyons Architects**  
*with Rounthwaite, Dick + Hadley*



## The Minto Center for Engineering Studies Addition

**B.008**

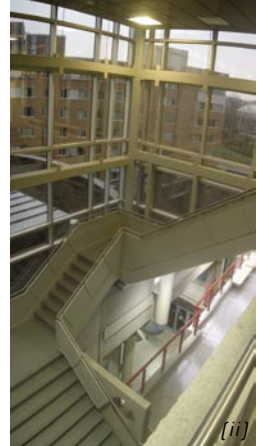
Carleton University  
Ottawa, Ontario

42,632 sqft

The addition of 3 floors on top of the existing building for additional classroom, lab and office space

No formal atrium space, yet 4 storeys of skylight openings follow a large stairwell on the north end of the building

**Completed 2000**  
**Griffiths Rankin Cook Architects**



## Azrieli Pavilion

**B.009**

Carleton University  
Ottawa, Ontario

35,000 sqft

4 storey building with specialized computer laboratories and workrooms, state-of-the-art classrooms, teaching studios and seminar rooms

No full building height spaces, although an extensive enclosed stair well runs up the side of the building connecting all floors together



**Completed 2002**  
**Moriyama + Teshima Architects with Hobin Architect + Assoc.**



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**B.010**

40,000 sqft

**Azrieli Theatre**

Carleton University  
Ottawa, Ontario



4 storey building with four large lecture halls, teaching studios and seminar rooms

2 storey basic atrium connecting the first and second levels together used as gathering space

**Completed 2002**

**Moriyama + Teshima Architects  
with Hobin Architect + Assoc.**



## National Wildlife Research Centre at the Nesbitt Building

**B.011**

Carleton University  
Ottawa, Ontario

60,000 sqft

4 storey building which houses 15 laboratories, a 1000 square foot greenhouse and a state of the art wildlife specimen storage facility along with office space

No full building height space although a small open space extends vertically beside the stairwell core

**Completed 2002**

**Diamond+Schmidt Architects**  
*with Katz Webster Clancey Architects*



## H M Tory Biology Building

**B.012**

Carleton University  
Ottawa, Ontario

80,000 sqft

Restoration and renovation of the original science building which now holds classrooms, biology teaching labs, and administrative offices

No atrium used in the original design or renovation

**Completed 2002**

**Edward J. Cuhaci + Assoc.**  
**Architects**





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**B.013**

5,000 sqft

**Nesbitt Biology Building Addition**

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Carleton University  
Ottawa, Ontario



Addition to the west end and along the north side of the existing Nesbitt Building, which houses a set of laboratories for habitat modeling and mapping, along with office space

No atrium used in the original design or renovation

**Completed 2004**  
**Diamond+Schmidt Architects**  
**with Katz Webster Clancey Architects**

## HP Science and Technology Center

**B.014**

Centennial College  
Scarborough, Ontario

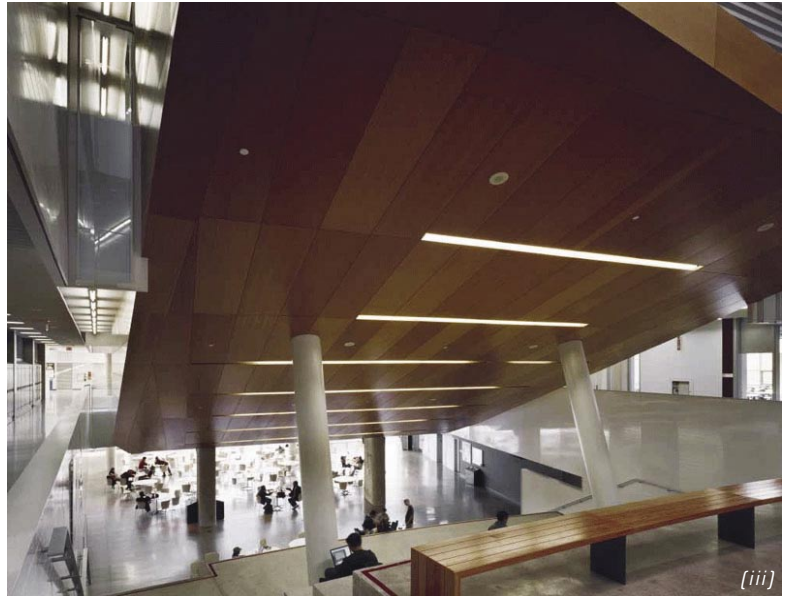
237,000 sqft

4 storey building consisting of classrooms, labs, offices, lecture hall and café and social spaces

A total of five atriums throughout the building which are used as part of the air movement system, and support distinct program spaces on their ground floor: labs, lounges, a café and gathering spaces

**Completed 2003**

**Kuwabara Payne McKenna  
Blumberg Architects with Stone  
Kohn McQuire Vogt Architects**



## B.015

115,000 sqft

## E Wing

Conestoga College  
Kitchener, Ontario



3 storey consisting of a 150-seat auditorium, 35 classrooms, faculty offices, meeting rooms, group work rooms, a student lounge and cafeteria

2 storey atrium corridor which runs along the north façade and becomes a part of the north entrance where it incorporates an open foyer and vertical circulation



**Completed 2002**  
**The Walter Fedy Partnership**





## Communication Arts 'M' Building

**B.016**

Fanshawe College  
London, Ontario

91,414 sqft

3 storey building with 2 radio stations, an in-house TV station, computer labs, production studios and faculty space

No atrium used in design

**Completed 2002**  
**architects Tillman - Ruth -**  
**Mocellin**



## 'F' Building West Addition

**B.017**

Fanshawe College  
London, Ontario

51,210 sqft

3 storey addition housing a variety of student services including Student Counseling, Computer Labs, Student Lounge space as well as offices

No atrium used in design

**Completed 2003**  
**architects Tillmann - Ruth -**  
**Mocellin**



**B.018**

104,498 sqft

## **Centre for Construction Trades and Technology 'T' Building**

Fanshawe College  
London, Ontario



3 storey building attached to the campus complex consisting of construction, plumbing and electrical labs, as well as classroom and office space

Connected 2 storey space starting at the main entrance and running across the front façade culminating at the west end in a full open atrium, used for circulation and daylight infiltration

**Completed 2006**  
**architects Tillmann - Ruth -**  
**Mocellin**



## 146 Kendal Avenue Casa Loma Campus

**B.019**

George Brown College  
Toronto, Ontario

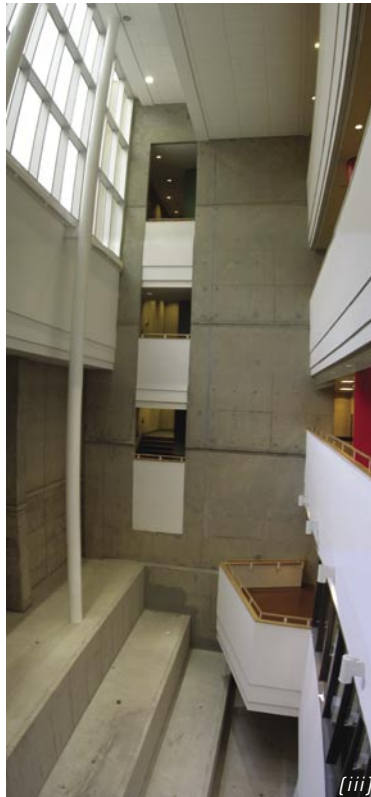
118,000 sqft

4 storey building with commercial and student spaces on the ground floor and classrooms and offices on the upper 2 floors

Full height basic atrium where it attaches to the existing campus buildings and a 2 storey circulation atrium used as an exhibition space which runs along Kendel St



**Completed 2003**  
**Moffat Kinoshita Architects**



**B.020**

48,000 sqft

## **Centre for Financial Services Education**

George Brown College  
Toronto, Ontario



5 storey building with classrooms, offices and student 'break out' rooms

No atrium used in design

**Completed 2003**  
**Moffat Kinoshita Architects**



## Centre for Technology Enhanced Learning

**B.021**

Georgian College  
Barrie, Ontario

100,000 sqft

3 storey building connected to the existing college complex, containing classrooms, a lecture hall and a 20,000 sqft library

A 2 storey circulation atrium at the entrance connecting the ground and second floor, as well as small inter-floor openings along the south wing façade connecting the 2nd and 3rd floors. Library area was 2 1/2 storeys high

**Completed 2003**  
**Curruthers Shaw + Partners**  
**Architects**



**B.022**

45,000 sqft

## **Computer Technology Centre Building 'F' Lakeshore Campus**

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Humber College  
Toronto, Ontario



3 storey masonry historic building renovated to house computer laboratories, tiered electronic classrooms, and common rooms

No atrium used in design

**Completed 2004**  
**Taylor/Hazell Architects**

## University of Guelph-Humber at Humber North Campus

**B.023**

Humber College  
Toronto, Ontario

133,130 sqft

4 storey building containing lecture halls, classrooms, specialized learning and teaching laboratories, computer labs, a café and offices

4 storey enhanced atrium in the centre of the north end of the building using a living wall bio filter to condition the air within the building, as well a 2 storey basic atrium at the south end, both used as main floor gathering space

**Completed 2004**

**Diamond+Schmidt Architects**  
*with Rieder, Hymmen + Lobban Architects*





## B.024

168,000 sqft

## Institute for Applied Health Studies

McMaster University  
Hamilton, Ontario



4 storey plus basement building, with classrooms, teaching labs, student work/lounge space, offices, a café and space for industrial partners - joint venture between Mohawk + McMaster

Large full building height circulation atrium in the heart of the building which joins with the entrance, used for lounge/work space with the café and vertical circulation

**Completed 2000**  
**Architect Unavailable**



## **AIC Wing – School of Business Expansion**

**B.025**

McMaster University  
Hamilton, Ontario

22,000 sqft

3 storey addition houses four new classrooms, labs, research areas, and office space

No atrium used in design of addition

**Completed 2002**  
**Chamberlain Architect**  
**Services Ltd.**



## **Arthur Bourns Building Expansion**

**B.026**

McMaster University  
Hamilton, Ontario

30,000 sqft

4 storey research facility built on the west wing of the existing building housing laboratories and meeting/seminar rooms.

No atrium used in design of addition

**Completed 2003**  
**Cianfrone Architect Inc**



**B.027**

36,000 sqft

## **Information Technology Building Extension**

McMaster University  
Hamilton, Ontario



3 storeys plus basement addition to contain 13 electrical and computer laboratories, a 200-seat lecture hall and office space

No atrium used in design of addition

**Completed 2004**  
**Chamberlain Architect**  
**Services Ltd.**



## James Stewart Centre for Mathematics

**B.028**

McMaster University  
Hamilton, Ontario

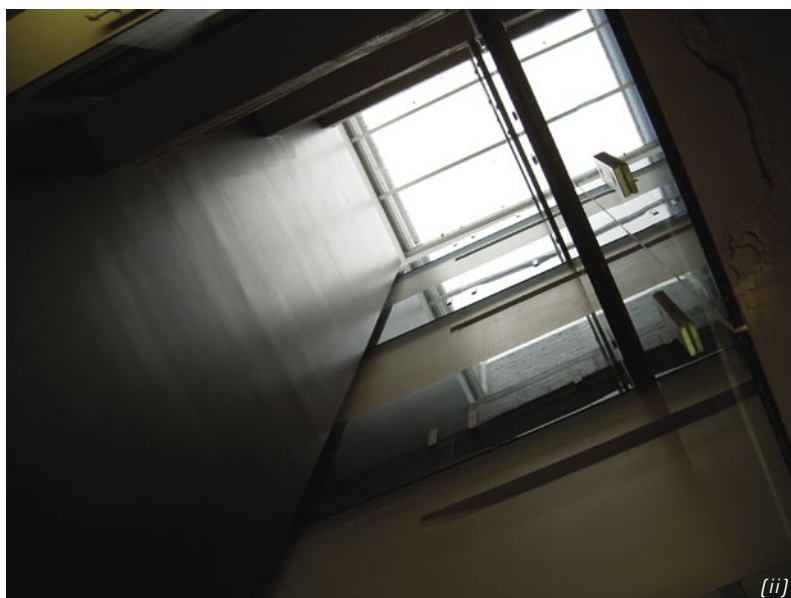
49,000 sqft

Renovated 3 storey plus basement historic building with new classrooms, faculty offices and math laboratories

Two small full building height basic atriums within the heart of the building, one starting at the basement level, the other on the ground floor, bringing light into circulation and social spaces



**Completed 2004**  
**Kuwabara Payne McKenna**  
**Blumberg Architects**





**B.029**

275,000 sqft

## **Michael G DeGroote Centre for Learning and Discovery**

McMaster University  
Hamilton, Ontario



5 floors of medical teaching, learning and research, with classrooms, lecture halls and a theatre on the lower floors, and labs and offices on the upper floors

4th to 5th floor basic atrium to light upper lab spaces with student lounge/work space on the 4th floor as well as a 3 storey ground floor basic atrium for receptions, resting and lounging

**Completed 2005  
NORR Ltd.**



## Information Technology Centre

Mohawk College  
Hamilton, Ontario

**B.030**

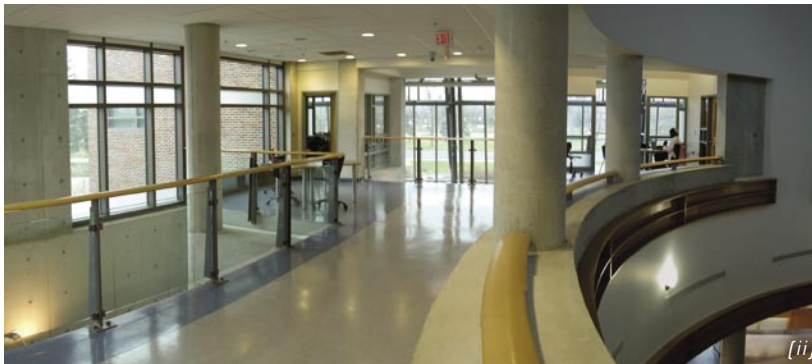
60,000 sqft

2 storey building with classrooms, computer labs, computer commons, student work/lounge areas, a café and the learning centre

3 full building height atrium spaces throughout the building, large east circulation atrium as part of entrance, 2 large north basic atriums which is a computer/work commons for students

**Completed 2004**

**Thier + Curran Architects**



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**B.031**

40,000 sqft

**Niagara Culinary Institute**

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Niagara College  
Niagara-on-the-Lake, Ontario



Single storey building with programmed basement, composed of a 100-seat dining room, food and bake labs, a culinary demonstration theatre, a service kitchen, classrooms, offices and meeting rooms

No atrium used in design - although dinning hall is a double height space which is part of the basement

**Completed 2004**  
**Moffat Kinoshita Architects**





## Sharp Centre for Design 100 McCaul Street Main Building

Ontario College of Art and Design  
Toronto, Ontario

**B.032**

66,898 sqft  
114,962 sqft

2 storey floating structure attached above the original renovated 4 storey building provides studio and teaching space (total 9 storeys high)

A circulation atrium within the original building's great hall and entrance which was part of the renovations constructed with the addition of the Sharp Center

**Completed 2004**

**Will Alsop Architect with  
Robbie/ Young + Wright  
Architects**



**B.033**

147,000 sqft

## **Chernoff Hall**

Queen's University  
Kingston, Ontario



5 storey new chemistry building which provides teaching and research labs, classroom facilities and offices

Central circulation atrium where the two wings of the building meet: rises the full height of the building, acting as a vertical + horizontal circulation hub, with a casual gathering space at the base

**Completed 2002**

**Brisbin Brook Beynon Architects**





## Goodes Hall

**B.034**

Queen's University  
Kingston, Ontario

112,805 sqft

3 storey addition to a Victorian schoolhouse containing many classrooms, lecture halls and 'break out' rooms for the university's business school

A central circulation atrium as part of the main reception hall and lounges which bridge the exterior of the old schoolhouse to the new section of the building

**Completed 2002**  
**The Ventin Group**



**B.035**

46,015 sqft

## **Cancer Research Institute**

Queen's University  
Kingston, Ontario

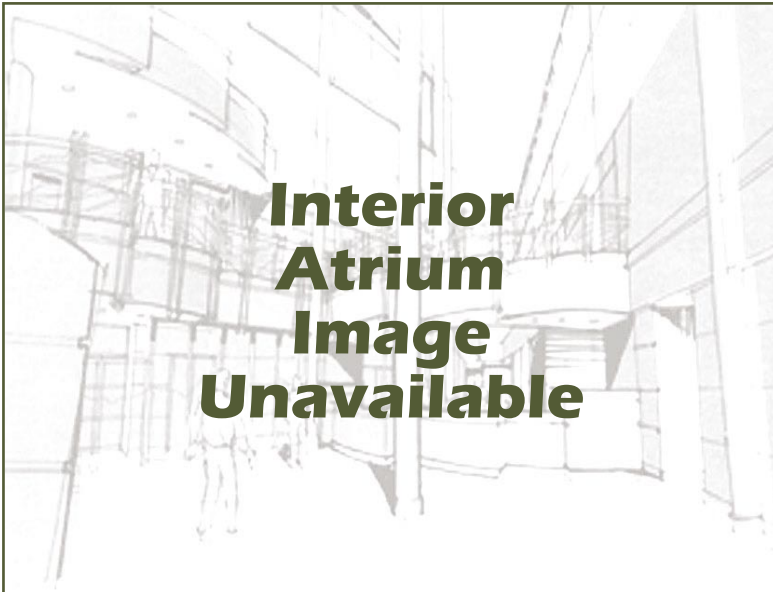


4 storey institute combines the studies at Queen's University with 3 international cancer research institutes

Large 3 storey basic atrium integrated as part of the research office space, used as lounge space and horizontal circulation

**Completed 2003**

**Diamond+Schmidt Architects  
with Shoalts & Zaback Architects**





## Beamish Munro Hall Integrated Learning Centre

**B.036**

Queen's University  
Kingston, Ontario

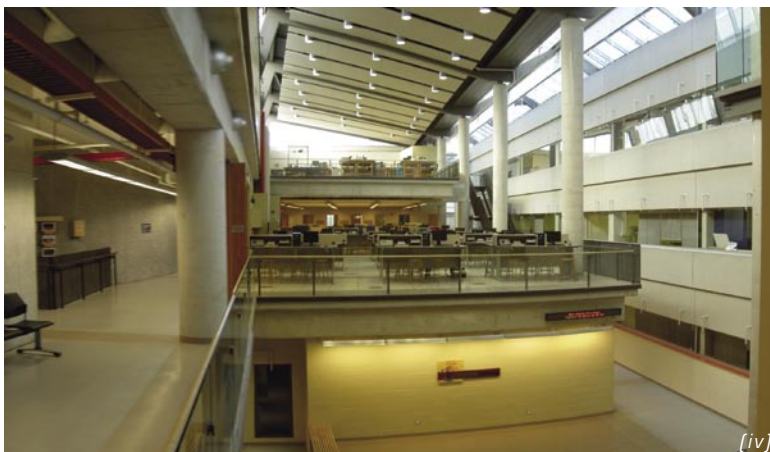
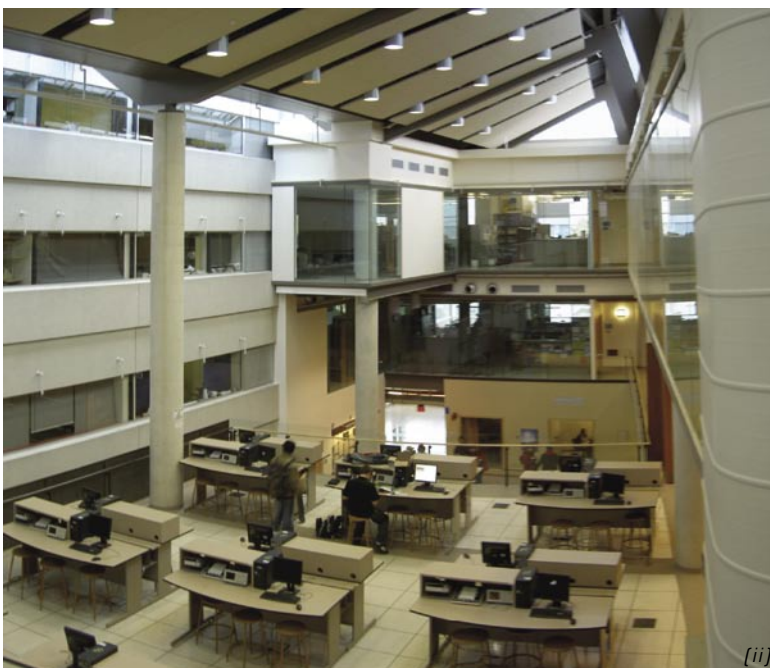
100,000 sqft

3 storey environmentally conscious designed building, for engineering undergrads, containing a design studio and a prototyping centre, group rooms and offices, a multimedia facility, a site investigation facility, and plazas or lab facilities

Large central enhanced atrium which is integrated with the programmed lab space, connecting all floors through the plazas (labs), complimented with a small entrance atrium containing a Bio-wall. Central atrium is also designed for air flow integration

**Completed 2004**

**Bregman + Hamann Architects**



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**B.037**

62,300 sqft

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**Gordon Hall / Gordon Annex**

Queen's University  
Kingston, Ontario



Full renovation of the existing buildings to house new facilities for the Registrar, Career Services and Graduate Studies

No atrium used in the original design or renovation

**Completed 2006**  
**Griffiths Rankin Cook Architects**

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**B.038**

3,500 sqft

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**Haynes Hall**

Queen's University  
Kingston, Ontario



Renovation of an acquired building for the growing Department of Family Medicine

No atrium used in the original design or renovation

**Completed 2006**  
**Shoalts & Zaback Architects**



## **Sally Horsfall Eaton Centre for Studies in Community Health**

**B.039**

Ryerson University  
Toronto, Ontario

72,000 sqft

2 floor addition on top of an existing building to provide classrooms and offices

No atrium used in design of addition

**Completed 2002**  
**Rounthwaite, Dick + Hadley**  
**Architects with**  
**Lett Smith Architects**



## **The Heidelberg Centre**

**B.040**

Ryerson University  
Toronto, Ontario

30,000 sqft

3 storey building with several multimedia labs, including pre-press, and press facilities

No atrium used in design

**Completed 2003**  
**Moffat Kinoshita Architects**



**B.041**

225,500 sqft

## **The George Vari Engineering and Computing Centre**

Ryerson University  
Toronto, Ontario



5 level building containing lecture rooms, laboratories, research facilities for PhD students and offices

Vertically connected basic atrium spaces in the lower lobby area as well as the 3 storey atrium room on the third floor

**Completed 2004**  
**Moriyama + Teshima Architects**



## Heaslip House

**B.042**

Ryerson University  
Toronto, Ontario

42,000 sqft

7 storey building housing the Chang School of Continuing Education and providing one-on-one learning spaces, meeting rooms and administration offices

No atrium used in design

**Completed 2005**  
**Rounthwaite, Dick + Hadley**  
**Architects with**  
**Lett Smith Architects**





**B.043**

210,000 sqft

## **Faculty of Business Building**

Ryerson University  
Toronto, Ontario



9 floor mixed use building contains classrooms, labs, offices, an auditorium and other meeting spaces on the top three floors

A large circulation atrium as part of the entrance on the ground floor connects the first 6 floors with a series of escalators, also noted is an open air courtyard sits within the 3 upper floors

**Completed 2006**

**Zeidler Partnership Architects  
with Queen's Quay Architects**





## Ford Centre for Excellence in Manufacturing

St. Clair College  
Windsor, Ontario

**B.044**

120,000 sqft

2 level building comprises training facilities for the automotive manufacturing industry, as well as classrooms, laboratories, offices, a café and a public Hall of Fame

Large circulation atrium rises over 2 storeys as part of the main entrance, used for vertical circulation for access to the second level of the automotive shops and greeting/gathering space

**Completed 2003**

**Norr Ltd *with* Archon Architect**



## B.045

75,000 sqft

## Link Building (Grey Wing)

St. Lawrence College  
Kingston, Ontario



2 storey building with classrooms, executive offices and meeting rooms; bridges two buildings on the Kingston campus

Circulation atrium space located at the widest portion of the building, used for horizontal and vertical circulation and daylight infiltration



**Completed 2004**  
**Diamond+Schmidt Architects**  
**with Shoalts & Zaback Architects**





## School of Business Newnham Campus Addition

Seneca College  
Toronto, Ontario

**B.046**

50,000 sqft

3 storey building plus basement with classrooms, computer labs, student 'break out' rooms and offices

Substantial 3 storey basic atrium which joins to the hallway on each floor and a student work space at the bottom

**Completed 2003**  
**architects Alliance**



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**B.047**

26,000 sqft

## **Animal Health Facility at King Campus**

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Seneca College  
King City, Ontario



Single storey building for the  
study of Veterinarian Health

No atrium used in design

**Completed 2004**  
**Architect Unavailable**

## Markham Campus

Seneca College  
Markham, Ontario

**B.048**

256,000 sqft

10 storey office building that was purchased and renovated to accommodate computer laboratories, classroom facilities and study areas

4 storey circulation atrium connecting the first 4 floors as part of the building's entrance, used for gathering and contains a large stairwell for vertical circulation

**Completed 2005**

**Moffat Kinoshita Architects**





**B.049**

91,000 sqft

## **Sheridan Centre for Animation and Emerging Technologies (SCAET)**

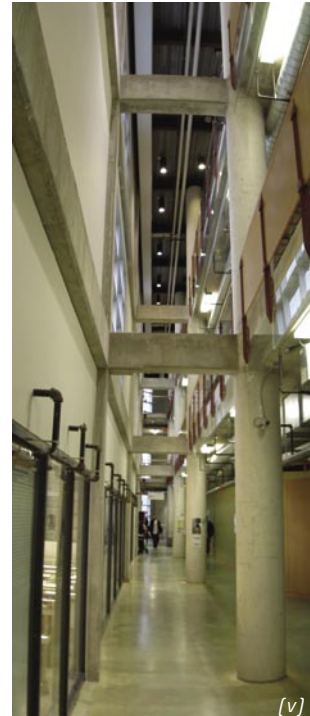
Sheridan College  
Oakville, Ontario



3 storey building with program filled basement, contains state-of-the-art computer laboratories, multi-media classrooms, and a 120-seat auditorium

Large circulation atrium within the middle of the building rises the height of the building and enlarges from the second to third floor. A second large atrium as part of the entrance with 2nd + 3rd floor plates stepped back, as well as vertical open space in front of façade walls

**Completed 2000**  
**Bregman + Hamann Architects**





## Sheldon Levy Centre CCIT Building

**B.050**

Sheridan College  
Oakville, Ontario

65,000 sqft

3 storey building housing a variety of computer labs - design, visualization and digital, a variety of studios - television, music and dance as well as a theatre-training complex

2 storey circulation atrium as part of the main entrance where two wings of the building come together, used as a circulation hub with an open stair between the first and second floor

**Completed 2001**  
**Zeidler Roberts Architects**



(i)



(ii)



(iii)



(iv)

**B.051**

18,000 sqft

## Centre for Manufacturing and Design Technologies

Sheridan College  
Brampton, Ontario



2 storey building with labs for training in the latest manufacturing and design processes

Full building height circulation atrium that runs in two directions as part of the hallways and contains a central stairway for vertical circulation

**Completed 2005**  
**Diamond+Schmidt**  
**Architects**





## Technology Wing Southernland Campus

Sir Sandford Fleming College  
Peterborough, Ontario

**B.052**

50,000 sqft

2 1/2 storey building containing engineering labs/workshops, classrooms, a computer commons, lecture theatre and faculty offices

Large atrium which runs across from the main entrance to the other end of the building used for circulation and gathering. Joined by a second smaller atrium space which is used as a hallway running perpendicular to the main atrium space, both atrium spaces are used in junction with 3 solar chimneys as enhanced air strategies

**Completed 2003**

**LINE Architect Inc.**



**B.053**

42,000 sqft

## **School of Environment and Natural Resource Science**

Sir Sandford Fleming College  
Lindsay, Ontario



Single storey building connected to the Frost campus complex, with research and computer labs, a computer commons, a library with administration space

Although a single storey building, there are double height hallways that have upper openings which help with passive cooling and ventilation. Also contains a double height glazed atrium lab



**Completed 2004**  
**Robbie Sane Architects Inc.**

## Chemical Sciences Building

Trent University  
Peterborough, Ontario

**B.054**

45,000 sqft

Single floor building with multi-storey ceilings consisting of research labs, chemistry teaching labs, and offices

Large circulation atrium beginning at the west end of the building acting as a double height circulation space and then continues down the main axis of the building as horizontal circulation

**Completed 2003**

**Teeple Architects with  
Shore Tilbe Irwin Partnership**





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**B.055**

**Peter Gzowski College**

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62,600 sqft  
140,000 sqft

Trent University  
Peterborough, Ontario



6 storey mixed use academic and student residence building with multiple lecture halls, classrooms, seminar rooms and offices

No atrium used in design

**Completed 2004**  
**Dunlop Architects with**  
**Two Row Architects**





## DNA Building

**B.056**

Trent University  
Peterborough, Ontario

57,900 sqft

2 storey building shared with the Ontario Ministry of Natural Resources containing wet and dry lab spaces, classrooms and faculty offices

Small full height basic atrium at the front of the building, used as an informal meeting area, beside - but not attached to - the enclosed entrance stair case

**Completed 2006**

**Shore Tilbe Irwin Partnership**



**B.057**

40,500 sqft

## **Access to Opportunities Program Building (ATOP)**

University of Guelph  
Guelph, Ontario



2 storey addition to the Thornbrough building, which consists of engineering and computing labs, a lecture theatre, and faculty space

Full height circulation atrium spaces at all stairwells as well as inter-floor openings down the main hallway axis connecting the two floors

**Completed 2000**  
**Teeple Architects**



## Rozanski Hall

University of Guelph  
Guelph, Ontario

**B.058**

76,700 sqft

1 1/2 storey building with multiple sized lecture halls and classrooms

Double height basic entrance atrium with a section of skylights, used as a central gathering space

**Completed 2002**  
**Robbie/Young + Wright**  
**Architects**



[i]



[ii]



**B.059**

15,000 sqft

## **Biodiversity Institute of Ontario (BIO)**

University of Guelph  
Guelph, Ontario



2 storey research building to house the Biodiversity Institute of Ontario facility

2 storey basic atrium in the center of the building which stretches across the short length of the building tying the two entrances together with a lounge/ gathering space



**Completed 2006**  
**Chamberlain Architect**  
**Services Ltd.**

## MacKinnon Extension

**B.060**

University of Guelph  
Guelph, Ontario

34,400 sqft

4 storey addition to the existing building offering 80 new faculty and staff offices

No atrium used in the design, although there is a three storey connected open stairwell



**Completed 2006**  
**Robbie/Young + Wright Architects**

## Science Complex Phase 1

**B.061**

University of Guelph  
Guelph, Ontario

170,000 sqft

5 storey teaching labs, research labs, computer labs, offices and an analysis and diagnostic centre

No atrium used in design - but will share an extremely large atrium between it and the other phases once all phases are complete  
See below.

**Completed 2004**  
**Robbie/Young + Wright Architects**





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**B.062**

230,000 sqft

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**Science Complex Phase 2A - 2B**

University of Guelph  
Guelph, Ontario



4 storey teaching labs, research labs, computer labs, student and faculty offices as well as meeting rooms or lounges

A 12,000 square-foot basic atrium which will be part of the overall complex will not be finished until Phase 2B is complete



**Completed 2006 (2007)**  
**Robbie/Young + Wright**  
**Architects**





## Science Building

**B.063**

University of Ontario Institute of Technology + Durham College  
Oshawa, Ontario

214, 374 sqft

4 floors of lecture halls, classrooms, research laboratories and specialty labs, meeting rooms, and offices

2 large atriums in the core of the building, used both programmatically as labs and lounges as well as for air movement through the building

**Completed 2003**  
**Diamond+Schmidt Architects**



## B.064

104,614 sqft

## Business and IT Building

University of Ontario Institute of Technology + Durham College  
Oshawa, Ontario



4 storey building with research laboratories, a lecture hall, classrooms, student lounge areas, and a food services cafe

Large central atrium rises the full height of the building, used as a student lounge on the ground floor and central stair circulation and basic air strategies

**Completed 2004**

**Diamond+Schmidt Architects**





## School of Information Technology and Engineering (SITE)

**B.065**

University of Ottawa  
Ottawa, Ontario

180,000 sqft

6 storey complex with classrooms,  
an amphitheatre, computer rooms,  
research laboratories and offices

Full height south-west atrium  
which runs the length of the  
building containing a student  
commons at the base and acts as  
a pre-conditioning air atrium. Also  
a small 2 storey north-east basic  
entrance atrium

**Completed 2002**  
**IKOY Architects**



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**B.066**

56,000 sqft

**Biology Building**

University of Ottawa  
Ottawa, Ontario



4 storey building with greenhouses on the roof, houses teaching, office and research space for biology studies and biology laboratories

No atrium used in design

**Completed 2003**

**Teeple Architects *with*  
Shore Tilbe Irwin Partnership**

## Biosciences Complex

**B.067**

University of Ottawa  
Ottawa, Ontario

190,000 sqft

5 storey building consisting of 10 biology labs and 2 large biochemistry labs, teaching labs as well as the associated support spaces

No atrium used in design

**Completed 2005**  
**Shore Tilbe Irwin Partnership**  
**with Cole + Assoc. Architects**



## Roger-Guindon Hall

**B.068**

University of Ottawa  
Ottawa, Ontario

98,000 sqft

4 level addition to existing medical research building, which includes new wet lab space for scientific research

No atrium used in design of addition

**Completed 2006**  
**Edward J. Cuhaci + Assoc.**  
**Architects**





**B.069**

110,000 sqft

## **The John and Edna Davenport Chemical Research Building**

University of Toronto  
Toronto, Ontario



2 storey addition atop the Lash Miller building providing chemistry labs, a large seminar room, a commons area and offices

2 storey basic atrium which uses the full height of the addition as it is located at the junction of the new wing, used as a gathering space for students

**Completed 2001**

**Diamond+Schmidt Architects**





## Bahen Centre for Information Technology

University of Toronto  
Toronto, Ontario

**B.070**

400,000 sqft

Building reaches as high as 8 stories complete with classrooms, lecture theatres, computer labs, meeting rooms and offices

Large atrium crosses through the building and along the adjoining face of existing building, used for circulation, informal gathering and for basic air handling (up to 8 stories)

**Completed 2002**

**Diamond+Schmidt Architects**



**B.071**

9,200 sqft

## **Centre for Applied Bioscience and Biotechnology**

University of Toronto - Mississauga  
Mississauga, Ontario



3 storey addition with new  
specialized research facility in  
biosciences and biotechnology

No atrium used in design

**Completed 2002**  
**Dunlop Architects**

## Sidney Smith Infill Project

University of Toronto  
Toronto, Ontario

**B.072**

6,150 sqft

3 storey infill project creates new faculty offices, 2 graduate suites, research and meeting rooms

Large 2 storey basic atrium connecting the ground and second floors used for informal meeting and social space

**Completed 2003**

**Ian McDonald Architect Inc**





## B.073

47,000 sqft

## Management Building

University of Toronto - Scarborough  
Scarborough, Ontario

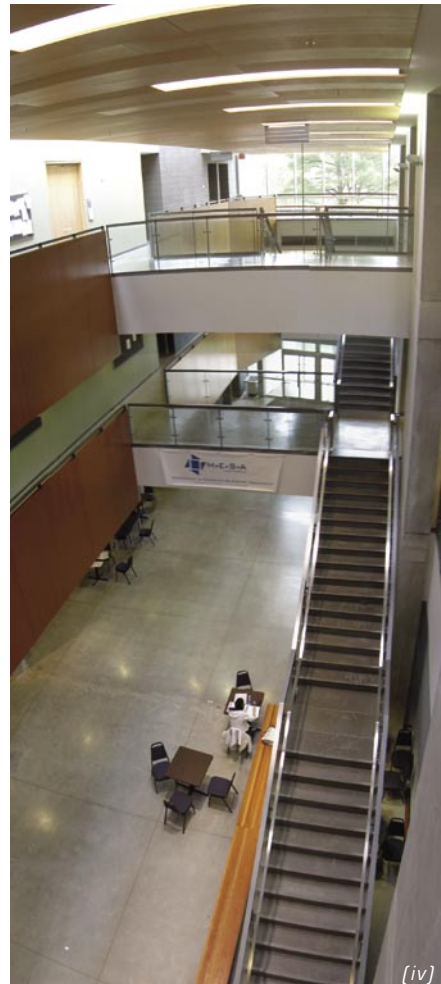
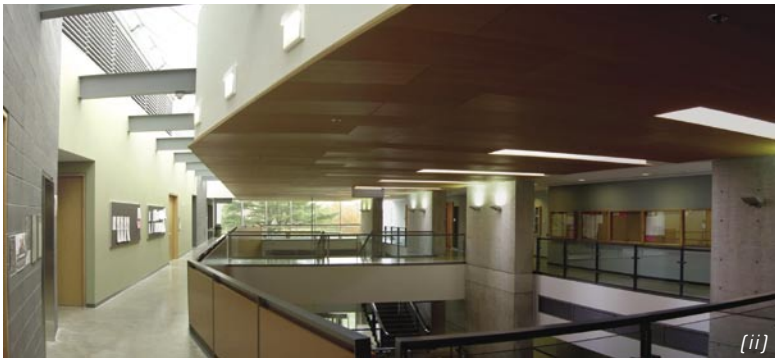


3 storey building with Case rooms, skills room, classrooms and academic division offices

3 storey, full height circulation atrium within the centre of the building, used as café and lounge space with all program spaces surrounding it

**Completed 2004**

**Kuwabara Payne McKenna  
Blumberg Architects**



## School of Continuing Studies

University of Toronto  
Toronto, Ontario

**B.074**

18,800 sqft

Renovation to existing 4 storey building to create a meeting place for students and instructors of the School of Continuing Studies

Large 2 storey basic atrium at the front of the building for reception and gathering space

**Completed 2004**

**Moriyama + Teshima Architects**



[i]



[ii]



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**B.075**

55,000 sqft

**Arts & Administration Building**

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University of Toronto - Scarborough  
Scarborough, Ontario



4 storey building with classrooms and teaching studios with specialized facilities for the visual and performing arts program, as well as offices and study spaces

No atrium used in design, although there is use of a small open stair between first and second floor

**Completed 2005**

**Montgomery Sisam Architects**

## The Terrence Donnelly Centre for Cellular and Biomolecular Research (CCBR)

**B.076**

University of Toronto  
Toronto, Ontario

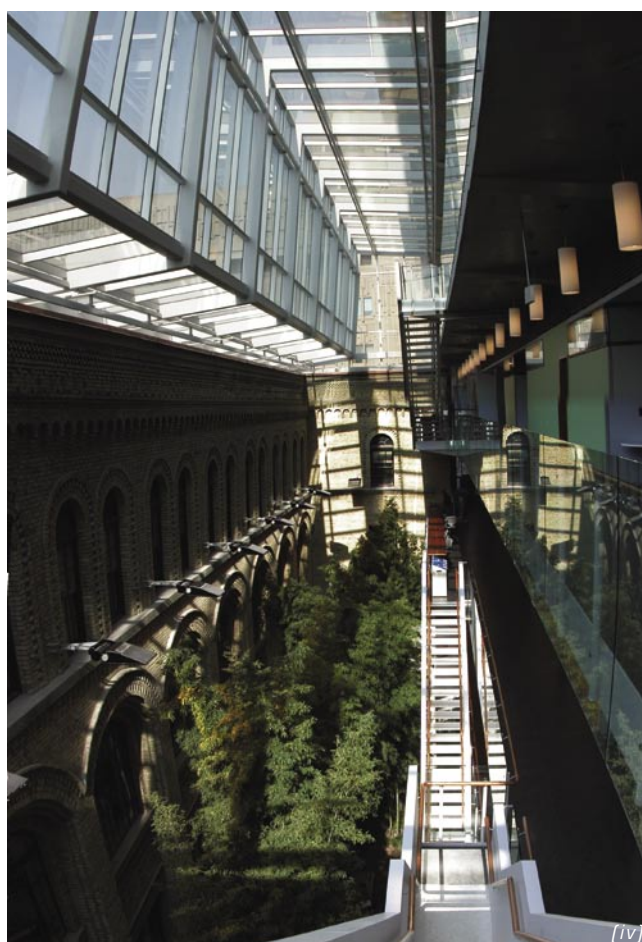
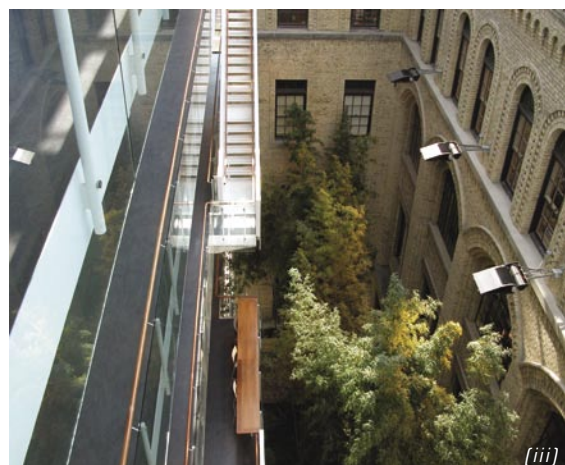
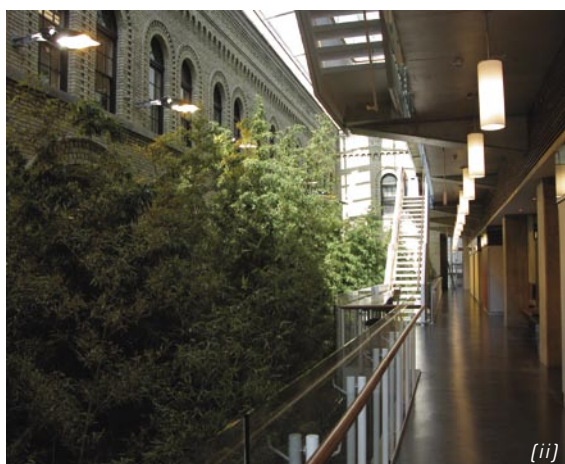
221,120 sqft

10 stories of open concept collaborative laboratory and teaching facilities

4 storey Donnelly Atrium runs between CCBR and the Rosebrugh building contains a bamboo garden with sitting spaces; with other garden atriums throughout the building, all used for light and basic air strategies

**Completed 2005**

**Behnisch, Behnisch + Partner**  
*with architects Alliance*





**B.077**

112,819 sqft

## Communication, Culture & Information Technology Building (CCIT)

University of Toronto - Mississauga  
Mississauga, Ontario



4 1/2 storey building containing multimedia lecture theatres, electronic classrooms and laboratories, as well as offices

Large full height basic atrium with gathering space on the ground floor, another full height circulation atrium used for vertical circulation, as well as a 3 storey basic atrium space at the south entrance

**Completed 2006**

**Saucier + Perrotte Architects**



## The Leslie L Dan Pharmacy Building

**B.078**

University of Toronto  
Toronto, Ontario

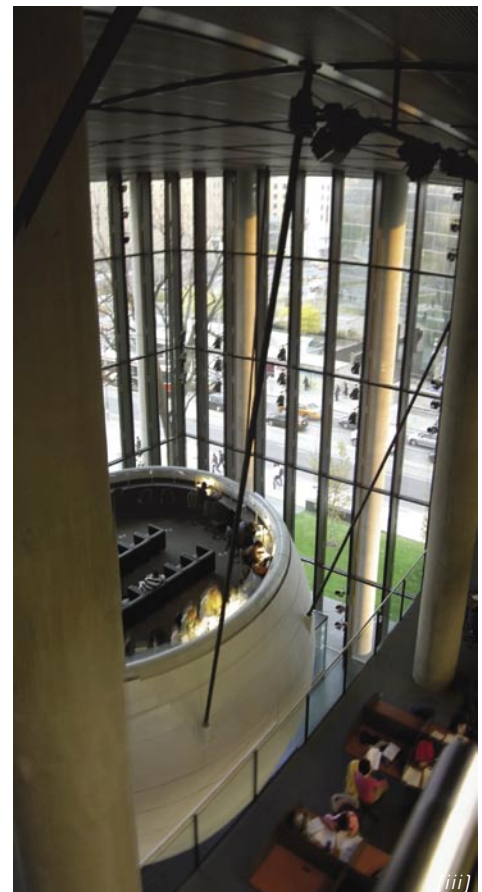
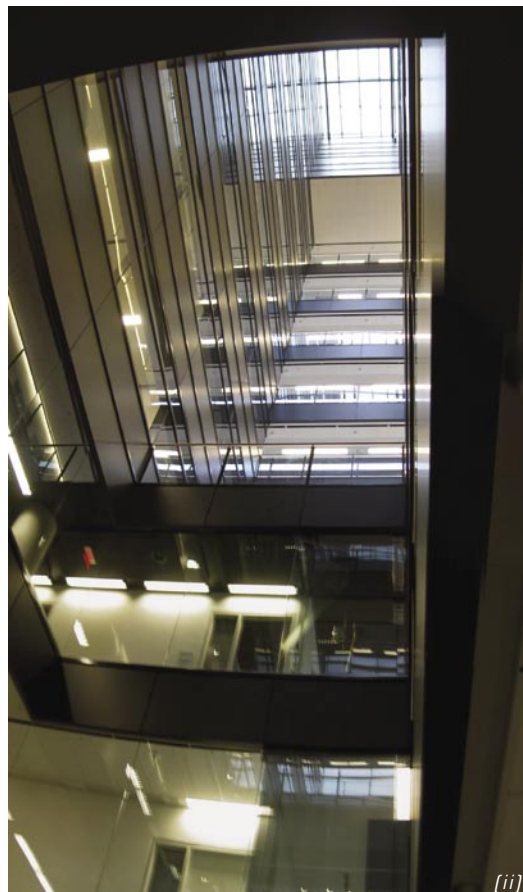
167,000 sqft

12 storey research and teaching laboratories and facilities, a new student services centre, faculty and support staff offices

Lower level entrance atrium incorporates many work/lounge and gathering spaces; as well as an atrium running the full height of the building for natural light and air movement

**Completed 2006**

**Fosters + Partners with  
Cannon Design**



**B.079**

45,500 sqft

## **Tatham Centre for Co-operative Education and Career Services**

University of Waterloo  
Waterloo, Ontario



3 storey building with programmed basement, geared towards the Coop process with interview rooms, meeting rooms, administrative office spaces, plus a coffee shop and lounges

A full height open stair, although no full height atrium space, two open spaces on the main floor, both 2 stories high, one of which is at the lower half of the open stair



**Completed 2002**  
**MacLennan Jaunkalns Miller**  
**Architects**



## Centre for Environmental and Information Technology (CEIT)

**B.080**

University of Waterloo  
Waterloo, Ontario

164,680 sqft

5 storey building with 20 classrooms, 44 laboratories, a lecture hall and the relocated Earth Sciences Museum

Through the center of the building runs the 3 storey March Networks Atrium, used for circulation and gathering space as well as housing exhibits from the Earth Sciences Museum

**Completed 2003**

**Teeple Architects with  
Shore Tilbe Irwin Partnership**



## B.081

85,000 sqft

## School of Architecture

University of Waterloo  
Waterloo, Ontario



3 storey renovated silk mill composed of design studios, classrooms, labs, offices, a library and lecture hall, as well as public gallery and cafe

Full height circulation atrium in the heart of the building tying the programs of the building together used as circulation and gathering/reception space

**Completed 2004**

**Stanley Saitowitz Office with  
Levitt Goodman Architects**



## **Lyle S Hallman Institute for Health Promotion**

**B.082**

University of Waterloo  
Waterloo, Ontario

24,780 sqft

3 storey building containing offices,  
meeting and seminar rooms for  
health informatics research

No atrium used in design

**Completed 2005**  
**RHL Architects Inc.**





**B.083**

18,000 sqft

## **Lawrence National Centre for Policy and Management**

University of Western Ontario  
London, Ontario



3 storey addition to the Ivey School of Business which added new office space and a large atrium

A large portion of the addition is a generous 3 storey basic atrium which reveals the refurbished existing building façade and offers a unique space for gathering and work/meeting space

**Completed 2002**  
**Wasylo Architect Inc.**



## Elizabeth A Labatt Hall King's College Campus

University of Western Ontario  
London, Ontario

**B.084**

65,000 sqft

2 storey building with tiered classrooms, a computer language lab, a large multi-purpose room, a café and faculty offices

Large full height basic atrium in the centre of the building used as student work and lounge spaces, including a café, and joins the main entrance

**Completed 2003**  
**Wasylo Architect Inc**





**B.085**

20,000 sqft

## **Spencer Engineering Building Addition**

University of Western Ontario  
London, Ontario



2 storey addition to the existing building to add more classrooms

No atrium used in design of addition

**Completed 2003**  
**architects Tillmann - Ruth -**  
**Mocellin**

## Thompson Engineering Building

University of Western Ontario  
London, Ontario

**B.086**

99,000 sqft

4 storey building with two 200-seat classrooms, studios, teaching and research laboratories, and faculty offices

Minor 2 storey basic atrium as part of the main entrance, used for gathering and connecting to the second floor lounge spaces



**Completed 2003**  
**Shore Tilbe Irwin Partnership**  
*with* **Malhotra Nicholson**  
**Architects**



**B.087**

78,000 sqft

## **Arthur and Sonia Labatt Health Sciences Building**

University of Western Ontario  
London, Ontario

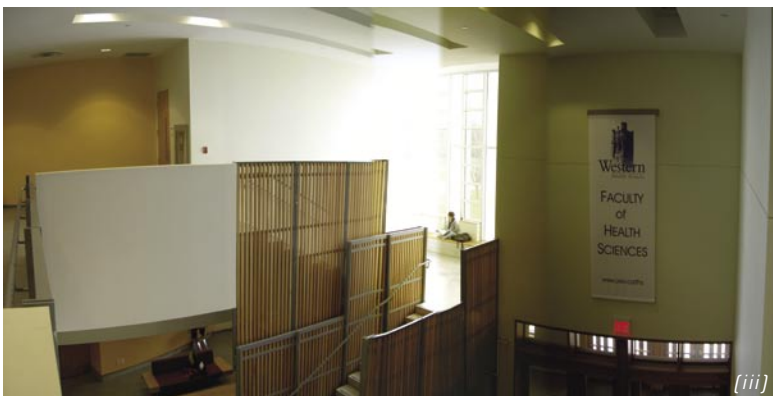


4 storey building with multiple lecture halls, laboratories, a café and offices

2 storey circulation atrium as part of the main entrance, including a stairwell to the second floor and adjoining student work/lounge space

**Completed 2004**

**Diamond+Schmidt Architect  
with Randy Wilson Architect**





## North Campus Building

University of Western Ontario  
London, Ontario

**B.088**

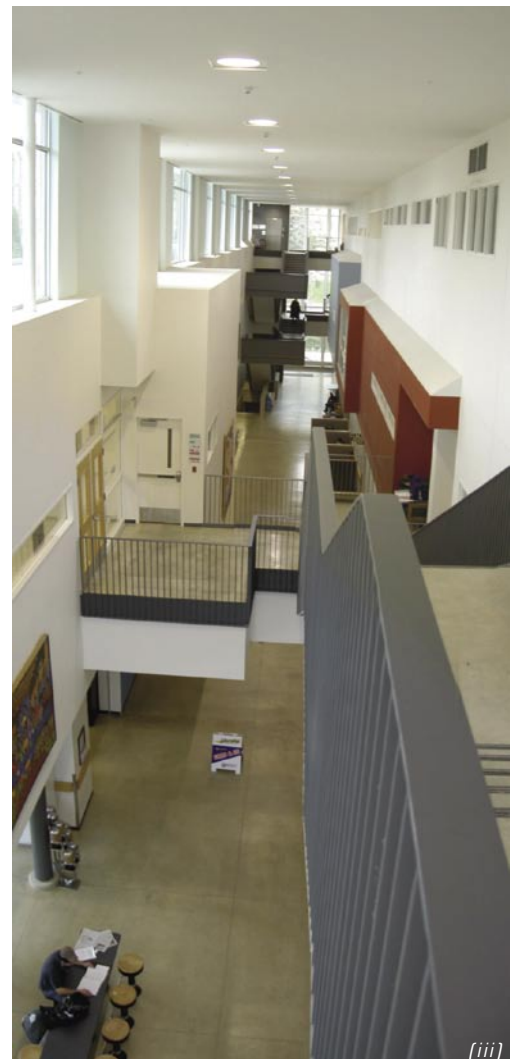
114,000 sqft

4 storey building consists of a 800-seat classroom, other smaller classrooms, laboratory and research space, new lounge areas, workrooms, and new office space for staff and faculty

A large 3 storey circulation atrium runs the length of the building containing multiple stairs and bridges to connect the different floors across the atrium, incorporates a café and lounge/work spaces on the main floor and joins the main entrance



**Completed 2005**  
**Teeple Architects with**  
**architects Tillman - Ruth -**  
**Mocellin**



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**B.089**

24,000 sqft

**Clinical Skills Building**

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University of Western Ontario  
London, Ontario



3 storey building which houses clinical rooms for Clinic Teaching as part of the Medical Sciences complex

No atrium used in design

**Completed 2006**  
**Architect Unavailable**



## Jackman Dramatic Art Centre

**B.090**

University of Windsor  
Windsor, Ontario

34,700 sqft

2 storey building attached to the existing Essex Hall contains teaching studios, a studio theatre and offices

Centrally located full building height circulation atrium used as informal lobby for the studio theatre, and vertical circulation. Also attaches to adjacent student work/lounge spaces

**Completed 2004**

**Diamond+Schmidt Architects  
with Di Malo Design Associates  
Architect**



**B.091**

66,400 sqft

## **Anthony P Toldo Health Education + Learning Centre**

University of Windsor  
Windsor, Ontario



3 storey building with multimedia classrooms, offices & labs for the Nursing Faculty

Large main basic atrium which runs centrally down the length of the building and across the front façade, used to bring daylight into the building, multiple student lounge/work spaces and main floor circulation

**Completed 2004**

**Diamond+Schmidt Architects  
with Di Malo Design Associates  
Architect**



## St. Michael's Campus

**B.092**

Wilfrid Laurier University  
Waterloo, Ontario

20,441 sqft

Acquired single storey elementary school building, renovated to house university classrooms and offices

No atrium used in the renovation

**Completed 2001**  
**Architect Unavailable**



## Arts C Wing Addition

**B.093**

Wilfrid Laurier University  
Waterloo, Ontario

29,558 sqft

2 storey addition which added six classrooms to existing arts wing

No atrium used in design, although at each end of the main hallway are rising glazed nooks with the one end interconnecting the 2 storeys



**Completed 2002**  
**Architect Unavailable**



**B.094**

39,472 sqft

## **Schlegel Building**

Wilfrid Laurier University  
Waterloo, Ontario



3 storey building with lecture theatres, classrooms and offices

Full height circulation atrium in the center of the building, with circulation running around the perimeter and a student workspace at the base

**Completed 2002**  
**Architect Unavailable**



## Bricker Academic Building

**B.095**

Wilfrid Laurier University  
Waterloo, Ontario

71,022 sqft

5 storey building consisting of lecture theatres, classrooms and offices

2 storey basic atrium space in the lobby connects entrances for both sides of the building and provides a gathering space

**Completed 2004**  
**Zeidler Grinnell Partnership**  
**Architects**





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**B.096**

22,372 sqft

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**Odeon Brantford Campus**

Wilfrid Laurier University  
Brantford, Ontario



Renovated movie theatre into a 2 storey building with lecture theatres, classrooms, a computer lab and offices

No atrium used in the renovation

**Completed 2004**  
**Architect Unavailable**

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**B.097**

43,000 sqft

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**Science Research Centre**

Wilfrid Laurier University  
Waterloo, Ontario



4 level building with research labs and offices

No atrium used in the design

**Completed 2004**  
**Zeidler Grinnell Partnership**  
**Architects**

## St. Jerome's Campus

**B.098**

Wilfrid Laurier University  
Kitchener, Ontario

39,182 sqft

Renovation of historic 4 storey building to house lecture theatres, classrooms, and offices

No atrium used in design, although the original open stair was kept in the renovation design

**Completed 2006**

**Cianfrone Architect Inc**



**B.099**

102,250 sqft

## **Computer Science Building**

York University  
Toronto, Ontario

4 level building made up of computer labs/classrooms, lecture theatres and offices

Central garden atrium and secondary atrium space as part of the cross building hallway. Both used for air movement including solar chimneys as part of the secondary atrium

**Completed 2001**  
**Busby + Associates with**  
**architects Alliance**





## Schulich School of Business

**B.100**

York University  
Toronto, Ontario

250,000 sqft

3 storey building with lecture halls, a two-level library, offices, and various common spaces - including the CIBC marketplace

Full height circulation atrium located where the wings of the building meet, used for circulation as well as formal and informal gathering space

**Completed 2003**

**Hariri Pontarini Architects with  
Robbie/Young + Wright  
Architects**



## B.101

360,000 sqft

## TEL Building

York University  
Toronto, Ontario



5 storey building with lecture halls, 31 classrooms, 40 computer labs, student and faculty offices

3 atriums which run the height of the building - the three-storey North Atrium, four-storey Central Atrium, and five-storey South Atrium all used for circulation and some gathering/lounge space and basic air moving strategies

**Completed 2003**

**Moriyama + Teshima Architects**





## Executive Learning Centre (Schulich School of Business)

**B.102**

York University  
Toronto, Ontario

80,000 sqft

12-storey tower, includes an auditorium, classrooms, several meeting rooms, and offices, as well as 60 executive style guest rooms and Executive Dining Room

No atrium used throughout the tower, but a large 3 storey space used as a formal dining room

**Completed 2004**

**Hariri Pontarini Architects with  
Robbie/Young + Wright  
Architects**



## Accolade East

**B.103**

York University  
Toronto, Ontario

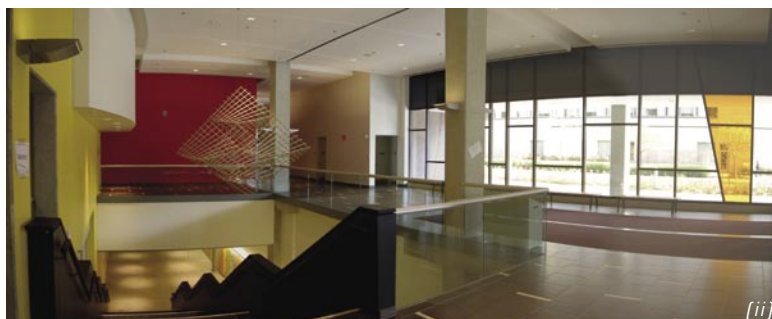
280,550 sqft

4 level building including theatre, recital hall, cinema/lecture hall, performance halls, lobby, specialized dance and music studios, as well as classrooms, labs and seminar rooms

No full height atrium spaces, although multiple 2 storey spaces connecting different sets of floors together used as circulation and gathering space

**Completed 2006**

**Bregman + Hamann Architects  
with Zeidler Partnership  
Architects**



## B.104

77,155 sqft

## Accolade West

York University  
Toronto, Ontario



4 level building including lecture halls, classrooms, labs, seminar rooms and a gallery

Large basic atrium space that begins on ground floor and further opens up on second and third floors, used as circulation and gathering space

**Completed 2006**

**Bregman + Hamann Architects  
with Zeidler Partnership  
Architects**







## **Appendix C :: Building Code for Atrium**

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## Building Code for Interconnected Floor Spaces

## C.1

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As all buildings found in the survey with atria have had to comply with the Ontario Building Code, the thesis investigation reviewed the building code to understand the fire related issues in the matter of interconnected floor spaces. Figures C.01 to C.04 feature excerpts from the Ontario Building Code<sup>1</sup> (OBC) which address fire safety for atrium type spaces.

Building fires are very serious issues when they occur in buildings with atrium or other interconnected spaces. This is mainly due to the ease smoke and fire spread, as the fire uses the atrium space to quickly move up and through the building. This was one of the main reasons that the initial designs and constructions of atria in England and France declined in the late nineteenth century. Over the years, technical advancements such as stronger, more fire resistant materials, as well as tested methods for fire proofing practices were developed to address building fire concerns. In conjunction with these technical developments, standardized fire regulations and codes have helped to ensure the integrity of atrium designs in the event of fire.

In the Ontario Building Code (OBC), an atrium space falls under the term 'interconnected floor space'. In part 3 of the OBC: Fire Protection, Occupant Safety and Accessibility, atria or interconnected floor spaces are addressed in section 3.2.8: Mezzanines and Openings through Floor Assemblies. Here the uses of interconnected floor spaces are given parameters to be adhered to maintain fire precautions. Most important are: space configurations, dealing with exits, the inclusion of sprinkler systems, and smoke control.

### 3.2.8. Mezzanines and Openings through Floor Assemblies

#### 3.2.8.1. Application

(1) Except as permitted by Article 3.2.8.2. and Sentence 3.3.4.2.(3), the portions of a floor area or a *mezzanine* that do not terminate at an exterior wall, a *firewall* or a vertical shaft shall

- (a) terminate at a vertical *fire separation* having a *fire-resistance rating* not less than that required for the floor assembly and extending from the floor assembly to the underside of the floor or roof assembly above, or
- (b) be protected in conformance with the requirements of Articles 3.2.8.3. to 3.2.8.11.

(2) The penetration of a floor assembly by an *exit* or a *vertical service space* shall conform to the requirements of Sections 3.4., 3.5. and 3.6.

(3) A *floor area* containing sleeping rooms in a building of Group B, Division 2 or 3 *major occupancy* shall not be constructed as part of an *interconnected floor space*.

(4) Except as permitted in Sentence (5), an elementary or secondary school shall not

- (a) contain an *interconnected floor space*, or
- (b) be located in an *interconnected floor space*.

(5) An *interconnected floor space* is permitted in an elementary or secondary school provided

- (a) the *interconnected floor space* consists of the *first storey*, and the *storey* next above or below it, but not both,
- (b) the *interconnected floor space* is *sprinklered*,
- (c) the portions of the upper *floor area* that do not terminate at an exterior wall, a *firewall* or a vertical shaft shall terminate at a vertical *fire separation* extending from the floor assembly to the underside of the floor or roof assembly above,
- (d) except as provided in Clause (e), the *fire separation* required in Clause (c) need not have a *fire-resistance rating*,
- (e) where a corridor is located immediately adjacent to the *fire separation* required in Clause (c), the *fire separation* shall have a *fire-resistance rating* of not less than 30 min, and
- (f) where a portion of a *floor area* is not within the *interconnected floor space*, the required *access to exit* from this portion of the *floor area* shall not lead through the *interconnected floor space*.

#### 3.2.8.2. Exceptions to Special Protection

(1) A *mezzanine* need not terminate at a vertical *fire separation* nor be protected in conformance with the requirements of Articles 3.2.8.3. to 3.2.8.11. provided the *mezzanine*

- (a) serves a Group A, Division 1 *major occupancy*,
- (b) serves a Group A, Division 3 *major occupancy* in a building not more than 2 *storeys* in *building height*, or
- (c) is not considered as a *storey* in Sentences 3.2.1.1.(3) or 3.2.1.1.(5) in calculating *building height* provided
  - (i) every point on the *mezzanine* is within 25 m (82 ft) of a point or points on the *mezzanine* perimeter from which, in the aggregate, an occupant may view 60% of the area of the room or *storey* in which the *mezzanine* is located, and
  - (ii) the *mezzanine* does not contain a Group B *occupancy*,
- (d) is not considered a *storey* in Sentence 3.2.1.1.(4) in calculating *building height* provided the *mezzanine* is not more than 500 m<sup>2</sup> (5,380 m<sup>2</sup>) in area and does not contain a Group B *occupancy*, or
- (e) is not considered a *storey* in calculating *building height* in Sentence 3.2.1.1.(8).

(2) Except for floors referred to in Sentence 3.1.10.3.(1) and Article 3.2.1.2., openings through a horizontal *fire separation* for vehicular ramps in a *storage garage* are not required to be protected with *closures* and need not conform to this Subsection.

(3) If a *closure* in an opening in a *fire separation* would disrupt the nature of a manufacturing process, such as a continuous flow of material from *storey* to *storey*, the *closure* for the opening is permitted to be omitted provided precautions are taken to offset the resulting hazard. (See Appendix A.)

(4) An *interconnected floor space* in a Group B, Division 1 *occupancy* need not conform to the requirements of Articles 3.2.8.3. to 3.2.8.11. provided the *interconnected floor space* does not interconnect more than 2 adjacent *storeys*.

(5) Except as permitted by Sentence (6), openings for stairways, escalators and inclined moving walks need not conform to the requirements in Articles 3.2.8.3. to 3.2.3.11. provided

- (a) the opening for each stairway, escalator or walk does not exceed 10 m<sup>2</sup> (108 ft<sup>2</sup>),

- (b) the *building* is *sprinklered* throughout, and
  - (c) the *interconnected floor space* contains only Group A, Division 1, 2 or 3, Group D or Group E *occupancies*.
- (6) An *interconnected floor space* need not conform to the requirements of Articles 3.2.8.3. to 3.2.8.11. provided
- (a) the *interconnected floor space* consists of the *first storey* and the *storey* next above or below it, but not both,
  - (b) the *interconnected floor space* is *sprinklered*, and
  - (c) the *interconnected floor space* contains only Group A, Division 1, 2 or 3, Group D, Group E, or Group F, Division 3 *occupancies*.
- (See Appendix A.)

### 3.2.8.3. Configuration

(1) In *buildings* constructed in conformance with Articles 3.2.8.4. to 3.2.8.11., the *unprotected openings* through floor assemblies in an *interconnected floor space* shall be of sufficient size and shall be positioned relative to each other so as to be capable of containing, within the full height of the *interconnected floor space*, a cylinder conforming to Sentence (2).

(2) The cylinder referred to in Sentence (1) shall have a cross-section that, where taken at a right angle to the longitudinal axis of such cylinder, is

- (a) a circle at least 9 m (29 ft 6 in) in diameter, or
- (b) an ellipse at least 7 m (23 ft) wide along the minor axis and at least 65 m<sup>2</sup> (700 ft<sup>2</sup>) in area. (see Appendix A)

### 3.2.8.4. Exits

(1) A *building* that is more than 18 m (59 ft 1 in) in height, measured between *grade* and the floor level of the top *storey*, and that contains an *interconnected floor space*, shall be designed to limit the passage of smoke from a fire into *exit* stairshafts opening into an *interconnected floor space* so that during a 2 h period after the start of fire, such stairshafts will not contain more than 1% by volume of contaminated air from the fire floor, assuming an outdoor temperature equal to the January design temperature on a 2.5% basis.

(2) Where a *building* containing an *interconnected floor space* is more than 75 m (246 ft 1 in) in height, measured between *grade* and the floor level of the top *storey*, the *exit* stairshaft protection required in Sentence (1) shall be accomplished by the provision, between each *floor area* and each *exit* stairshaft, of a vestibule provided with a mechanical air supply or with a vent opening to the outdoors.

- (3) Where a vestibule protecting an *exit* stairshaft is incorporated into the design of the *building* to meet the requirements of Sentences (1) or (2), such vestibule shall
- (a) be designed so that each doorway for a door opening into the vestibule is located at least 1 800 mm (5 ft 11 in) from a door or doors opening outward from the vestibule,
  - (b) be separated from the remainder of the *floor area* by a *fire separation* having a *fire-resistance rating* at least equal to that required for the *exit* which it serves except that the *fire-resistance rating* of a *fire separation* between the vestibule and a *public corridor* need not exceed 45 min, and
  - (c) not have a door or doors opening into more than one *exit* stairshaft.

(4) Except where *exits* serving the *floor area* are at ground level, the increased travel distance to *exits* permitted by Clause 3.4.2.5.(1)(c) shall not apply to a *floor area* within an *interconnected floor space*.

(5) Where a portion of a *floor area* is not within an *interconnected floor space*, required *access to exit* from such portion of a *floor area* shall not lead through an *interconnected floor space*.

(6) Except as provided in Sentences (7) and (8), portions of an *interconnected floor space* that have floor levels more than 18 m (59 ft 1 in) above *grade* shall be served by *exits* that provide at least 0.3 m<sup>2</sup> (3.2 ft<sup>2</sup>) of area of treads, landings and floor surface for each occupant of such portions of an *interconnected floor space*. (See Appendix A.)

(7) The requirements of Sentence (6) need not be applied where a *floor area* that is a portion of an *interconnected floor space* and that has a floor level more than 18 m (59 ft 1 in) above *grade* is separated from the remainder of the *interconnected floor space* by a *fire separation* having a *fire-resistance rating* of at least 1 h, except that no *fire-resistance rating* is required for such *fire separation* where all of the *major occupancies* contained within the *interconnected floor space* may be classified as light hazard *occupancies* in conformance with Appendix A of NFPA 13 "Standard for the Installation of Sprinkler Systems".

(8) The requirements of Sentence (6) need not be applied where the *exit* stairs that serve *interconnected floor spaces* are designed so that the required width of each stair is cumulative.

**3.2.8.5. Elevators**

(1) Except as provided in Sentence (2), where an elevator shaft opens into an *interconnected floor space* and into *storeys* that are above such space and that have floor levels more than 18 m (59 ft 1 in) above *grade*, either the elevator doors opening into the *interconnected floor space* or the elevator doors opening into the *storeys* above the *interconnected floor space* shall be protected by vestibules that

- (a) are designed to restrict the passage of contaminated air to the limit described in Sentence 3.2.8.4.(1), and
- (b) conform to the requirements of Sentence 3.2.8.4.(3).

(2) Where elevator doors opening into an *interconnected floor space* are protected by vestibules in conformance with Sentence (1), the elevator doors opening into the lowest *storey* of the *interconnected floor space* need not be protected by such vestibules.

**3.2.8.6. Group B Sleeping Rooms**

(1) Openings provided for access between an *interconnected floor space* and a *building* or a portion of a *building* containing Group B *major occupancy* sleeping rooms shall be provided with vestibules that are provided with a mechanical air supply and that are designed

- (a) to restrict the passage of smoke from the *interconnected floor space* into the area containing sleeping rooms in accordance with the limits described in Sentence 3.2.8.4.(1), and
- (b) in conformance with Clause 3.2.8.4.(3)(a).

**3.2.8.7. Sprinklers**

(1) In a *building* containing an *interconnected floor space*, *storeys* that are wholly or partially within an *interconnected floor space* and all *storeys* below an *interconnected floor space* shall be *sprinklered*.

(2) In a *building* containing an *interconnected floor space*

- (a) waterflow alarm signals from sprinkler systems shall be transmitted to the fire department in conformance with Sentence 3.2.4.7.(4), and
- (b) sprinkler systems shall be electrically supervised as required in Sentence 3.2.4.9.(2).

**3.2.8.8. Fire Alarm and Detection System**

(1) A *building* containing an *interconnected floor space* shall be provided with

- (a) a fire alarm system and electrically supervised annunciator conforming to Subsection 3.2.4.,
- (b) a system of *smoke detectors* located
  - (i) on the ceiling of each *storey* in the vicinity of the openings through floor assemblies described in Article 3.2.8.3., except within dwelling units, *heat detectors* may be installed instead of *smoke detectors*, and
  - (ii) as required for the activation of the smoke control system described in Sentences (5), (6) and (7) of Article 3.2.8.9. (see Appendix A), and
- (c) facilities for transmitting a signal to the fire department in conformance with Article 3.2.4.7.

**3.2.8.9. Smoke Control**

(1) A smoke control system conforming to Sentences (2) to (8) shall be designed to control the movement of smoke within a *building* containing an *interconnected floor space*.

(2) The design of the smoke control system shall assume an outdoor temperature equal to the January design temperature on a 2.5% basis.

(3) Upon activation of the sprinkler system or automatic detection of smoke by at least two *smoke detectors* in a single zone within an *interconnected floor space*, the system shall

- (a) stop air moving fans which provide for the normal exhausting or re-circulating of air in an *interconnected floor space*,
- (b) activate *exit* stairshaft protection required in Article 3.2.8.4.,
- (c) activate elevator protection required in Article 3.2.8.5., and
- (d) activate the vestibule air supply required in Sentence 3.2.8.6.(1).

(4) A *building* containing an *interconnected floor space* may be designed so that, in the event of a fire arising in a *floor area* or part of a *floor area* within the *interconnected floor space*, automatic detection of such fire will activate air handling equipment that

- (a) extracts air directly from such *floor area* or part of a *floor area* at the rate of at least 6 air changes per hour, and
- (b) supplies air in sufficient quantities and at appropriate locations to prevent smoke from passing out of such



*floor area* into other portions of the *interconnected floor space*.

(5) For purposes of Sentences (6) and (7), the volume of an *interconnected floor space* need not include the aggregate volume of those *floor areas* or portions of *floor areas* designed to have zoned air extraction in accordance with Sentence (4).

(6) A mechanical exhaust shall be provided to remove air at the top of an *interconnected floor space* at the rate of at least 6 air changes per hour, except that where the volume of the *interconnected floor space* exceeds 17 000 m<sup>3</sup> (600,000 ft<sup>3</sup>), only 4 air changes per hour need be provided.

(7) Except where zoned mechanical exhaust described in Sentence (4) has been activated, upon automatic detection of smoke within the volume of the *interconnected floor space*, the mechanical exhaust described in Sentence (6) shall be automatically activated and supply air shall be provided in sufficient quantity and at appropriate locations to allow a consistent rate of removal of smoke throughout the volume of the *interconnected floor space*.

(8) Overriding manual controls for the smoke control system shall be provided for fire department use at an acceptable location in the vicinity of the fire alarm annunciator.

### 3.2.8.10. Emergency Power Supply

(1) In a *building* that is more than 18 m (59 ft 1 in) in height, measured between *grade* and the floor level of the top *storey*, an emergency power supply capable of operating under a full load for at least 2 h shall be provided by an emergency generator or by a separate service not supplied by the same substation as the primary source for fans required for smoke control purposes in Articles 3.2.8.4., 3.2.8.5., 3.2.8.6. and 3.2.8.9.

### 3.2.8.11. Testing

(1) The systems for smoke control and venting described in Articles 3.2.8.4., 3.2.8.5., 3.2.8.6. and 3.2.8.9. shall be tested to ensure satisfactory operation.

## 3.2.9. Standpipe Systems

### 3.2.9.1. Where Required

(1) Except as provided in Sentences (4) to (7), a standpipe system shall be installed in every *building* that

- (a) is more than 3 *storeys* in *building height*,
- (b) is more than 14 m (45 ft 11 in) high measured between *grade* and the ceiling of the top *storey*, or
- (c) is not more than 14 m (45 ft 11 in) high measured between *grade* and the ceiling of the top *storey* but has a *building area* exceeding the area shown in Table 3.2.9.1. for the applicable *building height* if the *building* is not *sprinklered*.

(2) A standpipe system shall be installed in every *basement* of a *building* that requires a standpipe system above *grade*.

(3) A standpipe system shall be installed in every *basement* of a *building* that is regulated by Sentence 3.2.2.15.(2).

**Table 3.2.9.1.**  
**Building Limits without Standpipe Systems**  
Forming Part of Sentence 3.2.9.1.(1)

Occupancy Classification	Building Area, m <sup>2</sup> (ft <sup>2</sup> )		
	1 Storey	2 Storeys	3 Storeys
A	2 500 (24,200)	2 000 (21,500)	1 500 (16,100)
C	2 000 (21,500)	1 500 (16,100)	1 000 (10,800)
D	4 000 (43,100)	3 000 (32,300)	2 000 (21,500)
F, Division 2	2 000 (21,500)	1 500 (16,100)	1 000 (10,800)
F, Division 3	3 000 (32,300)	2 000 (21,500)	1 000 (10,800)
Column 1	2	3	4

(4) A standpipe system is not required to be installed in the lowest *storey* in a *building* if this *storey* is a *service room* which has an area not more than 50 m<sup>2</sup> (538 ft<sup>2</sup>).

(5) A standpipe system is not required to be installed in a roof-top enclosure if this enclosure has an area not more than 50 m<sup>2</sup> (538 m<sup>2</sup>).

(6) A standpipe system is not required to be installed in a *storage garage* conforming to Article 3.2.2.83. provided the *building* is not more than 15 m (49 ft 3 in) high.

(7) A standpipe system is not required to be installed in a *dwelling unit* which

- (a) extends not more than 3 *storeys* above adjacent ground level,
- (b) is completely cut off from the remainder of the *building* so that there is no access to the remainder of the *building*, and
- (c) has direct access to its interior by means of an exterior doorway located not more than 1 500 mm (4

## Endnotes

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- <sup>1</sup> Ontario. Housing Development and Buildings Branch, *Ontario Building Code 1997 : Containing the Building Code Act Reg. 40397* (Toronto: Ministry of Municipal Affairs and Housing, Housing Development and Buildings Branch, 1997), 3-78 - 3-81.

## **Appendix D :: Air and Building Relationships**

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As the thesis study progressed, the need for a better understanding of both air movement and building ventilation was required in order to properly consider criteria used in the study group of buildings. This appendix begins by outlining the principles, characteristics and forces of air movement and their relationship with buildings. It continues on to examine our past experiences with ventilation, noting the factors which have directed our choices in modern day ventilating systems.

## Air as Experience

## D.1

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Although people may not make note of it very often, our experience with air is continuous. The best perception of air occurs outdoors, whether it is the leaves on the trees, dust kicked up by a passing car or a flag blowing in the wind. The high velocity of air outdoors tends to offer more force, which is easily observed through objects interacting with the wind. Alternatively, air can be perceived through its comforting or discomforting effect when outdoors: as hot humid days with no wind create a thick, suffocating sensation; while a light breeze can be pleasant and cooling, stronger winds are chilling and uncomfortable, especially in cold winter months. As a result, air movement can be seen to greatly affect the comfort of an individual.

Unfortunately this is not the case for indoor environments, although similar factors affect the comfort level of the space, the air movement within an enclosure is rarely perceivable. This is the intention, as slower levels of air movement indoors are not distracting to the occupants of the building. Therefore, the perception of air flow indoors is anything but straightforward,



fig. D.01 - Opening a window is the simplest and most idyllic way to bring in some fresh air.



which is why air movement must be fully contemplated at the design stage for it to be a successful experience.

### The Need for Fresh Air

Each day people consume 10 times more air than food or water (by volume), making the need for fresh air quite significant.<sup>1</sup> A continually renewed dose of fresh, oxygenated air is crucial to the environmental requirements for sustaining human life. Within the spaces of buildings, oxygen in the air is partially replaced by carbon dioxide through the repeated respiration of occupants. Further, air can accumulate bacteria and viruses, and pick up odours from sweating, smoking, cooking, toilet functions, and other processes. These same processes will release water vapour into the air increasing its water content and some will even increase the thermal value as heat is given off and absorbed into the air. Air will also collect gaseous pollutants from off gassing of materials and particles of dust and dirt. As a result, it becomes clear that the need for ventilation is very important within the design of the building and can determine how successfully it will function – especially how the inhabitant experiences it.

Yet air and its movement around us are difficult to perceive, despite their importance. Therefore our ability to judge and measure air properties and movement is dependent upon the help of technical equipment. We know that the air movement in a building must occur at a continuous and steady rate to insure that no air contaminants are allowed to build up. How can we ensure that this is being accomplished, especially while still working at a design phase?

### Recommended Ventilation Rates

Optimum indoor air quality may be defined as air which contains little to none of the aforementioned pollutants. The quantity of ventilation needed to ensure an acceptable IAQ depends on the amount and the nature of the dominant pollutant source in a space. Determining the correct ventilation rate can be a complex task, as there are numerous pollutants of potential concern, each having poorly characterized emission rates, and poorly defined acceptable levels of exposure. Although in most cases, the minimum ventilation rates needed for indoor air quality are easily reached and can be increased in order to achieve other goals such as heating or cooling.

Recommended rates of ventilation can be found in Table D.1 (non-residential) and Table D.2 (residential). Although very small amounts of outdoor air will provide sufficient oxygen, and

although body odour control is usually achievable at a rate of from 3 to 4.5 L/s (litres per second) of outdoor air per occupant, outdoor air has more to do than provide oxygen and control odours. Defining minimum outdoor air supply rates has proven to be a controversial task. The current ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ventilation standard (Standard 62.1-2004—for other than low-rise residential buildings) establishes minimum rates (Table D.2) on the basis of an occupancy component and a building component in recognition of these distinct contaminant sources.<sup>2</sup>

In practice, ventilation rates are often measured by air change rates defined as the number of complete volume changes a space experiences due to ventilation each hour. See formula below.

$$\text{ACH} = \frac{\text{cfm} \times 60\text{min/hr}}{\text{volume of space ventilated (cf)}}$$

$$\text{ACH} = \frac{\text{l/s} \times 3600 \text{ sec/hr}}{\text{volume of space ventilated (m}^3\text{)}}$$

Although our better building techniques for tighter buildings are great for reducing heat loss due to convection, we are now faced with the need to deal with the realities of our snug construction: we can no longer depend on leaking buildings to provide the air exchanges needed for ventilating the spaces we inhabit as we once did. Consequently it is now becoming mandated for ventilation to be included in all buildings to deal with this fact. As a result, mechanically run systems are the first to be added to the designed ventilation method to accommodate this requirement, which in turn increases the energy load drawn from the building.

## Indoor Air Quality

Indoor air quality (IAQ) has always been something to manage in enclosed man-made structures. This issue was first brought to light and addressed around the time of the industrial revolution as it was part of what initially led to the implementation of mechanical ventilation (the history of such will be covered in the following chapter). Several trends have combined to bring indoor air quality (IAQ) concerns back into focus. First, an increasingly large percentage of people's time is now spent indoors in more tightly controlled environments: the spaces we live in, work in, and even those used for recreation, especially

Table D.1 - Minimum Ventilation Rates in Breathing Zone

Occupancy Category	People Outdoor Air Rate				Area Outdoor Air Rate				Default Values			
	$R_p$		$R_a$		Notes		Occupant Density		Combined Outdoor Air Rate			
	cfm/Person	L/s Person	cfm/ft <sup>2</sup>	L/s m <sup>2</sup>			#/1000 ft <sup>2</sup>	cfm/Person	L/s Person			
<b>Correctional Facilities</b>												
Cell	5	2.5	0.12	0.6			25	10	4.9			
Day room	5	2.5	0.06	0.3			30	7	3.5			
Guard stations	5	2.5	0.06	0.3			15	9	4.5			
Booking/waiting	7.5	3.8	0.06	0.3			50	9	4.4			
<b>Educational Facilities</b>												
Daycare (through age 4)	10	5	0.18	0.9			25	17	8.6			
Classrooms (ages 5–8)	10	5	0.12	0.6			25	15	7.4			
Classrooms (age 9 plus)	10	5	0.12	0.6			35	13	6.7			
Lecture classroom	7.5	3.8	0.06	0.3			65	8	4.3			
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3			150	8	4.0			
Art classroom	10	5	0.18	0.9			20	19	9.5			
Science laboratories	10	5	0.18	0.9			25	17	8.6			
Wood/metal shop	10	5	0.18	0.9			20	19	9.5			
Computer lab	10	5	0.12	0.6			25	15	7.4			
Media center	10	5	0.12	0.6	A		25	15	7.4			
Music/theater/dance	10	5	0.06	0.3			35	12	5.9			
Multi-use assembly	7.5	3.8	0.06	0.3			100	8	4.1			
<b>Food and Beverage Service</b>												
Restaurant dining rooms	7.5	3.8	0.18	0.9			70	10	5.1			
Cafeteria/fast food dining	7.5	3.8	0.18	0.9			100	9	4.7			
Bars, cocktail lounges	7.5	3.8	0.18	0.9			100	9	4.7			
<b>General</b>												
Conference/meeting	5	2.5	0.06	0.3			50	6	3.1			
Corridors	—	—	0.06	0.3			—	—	—			
Storage rooms	—	—	0.12	0.6	B		—	—	—			

Table D.1 - Minimum Ventilation Rates in Breathing Zone (continued)

Occupancy Category	People Outdoor Air Rate			Area Outdoor Air Rate			Default Values		
	cfm/Person	L/s Person	R <sub>p</sub>	cfm/ft <sup>2</sup>	R <sub>a</sub>	L/s m <sup>2</sup>	Notes	Occupant Density #/1000 ft <sup>2</sup>	Combined Outdoor Air Rate cfm/Person L/s Person
<b>Hotels, Motels, Resorts, Dormitories</b>									
Bedroom/living room	5	2.5		0.06	0.3			10	11 5.5
Barracks sleeping areas	5	2.5		0.06	0.3			20	8 4
Lobbies/prefunction	7.5	3.8		0.06	0.3			30	10 4.8
Multi-purpose assembly	5	2.5		0.06	0.3			120	6 2.8
<b>Office Buildings</b>									
Office space	5	2.5		0.06	0.3			5	17 8.5
Reception areas	5	2.5		0.06	0.3			30	7 3.5
Telephone/data entry	5	2.5		0.06	0.3			60	6 3
Main entry lobbies	5	2.5		0.06	0.3			10	11 5.5
<b>Miscellaneous Spaces</b>									
Bank vaults/safe deposit	5	2.5		0.06	0.3			5	17 8.5
Computer (not printing)	5	2.5		0.06	0.3			4	20 10
Pharmacy (prep. area)	5	2.5		0.18	0.9			10	23 11.5
Photo studios	5	2.5		0.12	0.6			10	17 8.5
Shipping/receiving	—	—		0.12	0.6		B	—	
Transportation waiting	7.5	3.8		0.06	0.3			100	8 4.1
Warehouses	—	—		0.06	0.3		B	—	
<b>Public Assembly Spaces</b>									
Auditorium seating area	5.0	2.5		0.06	0.3			150	5 2.7
Places of religious worship	5.0	2.5		0.06	0.3			120	6 2.8
Courtrooms	5.0	2.5		0.06	0.3			70	6 2.9
Legislative chambers	5.0	2.5		0.06	0.3			50	6 3.1
Libraries	5.0	2.5		0.12	0.6			10	17 8.5
Lobbies	5.0	2.5		0.06	0.3			150	5 2.7
Museums (children's)	7.5	3.8		0.12	0.6			40	11 5.3
Museums/galleries	7.5	3.8		0.06	0.3			40	9 4.6

Table D.1 - Minimum Ventilation Rates in Breathing Zone (continued)

Occupancy Category	People Outdoor Air Rate			Area Outdoor Air Rate			Default Values		
	$R_p$		$R_a$	$R_a$		Notes	Occupant		Combined Outdoor Air Rate
	cfm/Person	L/s Person		cfm/ft <sup>2</sup>	L/s m <sup>2</sup>		Density #/1000 ft <sup>3</sup>	cfm/Person	
<b>Retail</b>									
Sales (except as below)	7.5	3.8	0.12	0.6	15			16	7.8
Mall common areas	7.5	3.8	0.06	0.3	40			9	4.6
Barber shop	7.5	3.8	0.06	0.3	25			10	5
Beauty and nail salons	20	10	0.12	0.6	25			25	12.4
Pet shops (animal areas)	7.5	3.8	0.18	0.9	10			26	12.8
Supermarket	7.5	3.8	0.06	0.3	8			15	7.6
Coin-operated laundries	7.5	3.8	0.06	0.3	20			11	5.3
<b>Sports and Entertainment</b>									
Sports arena (play area)	—	—	0.3	1.5	—				
Gym, stadium (play area)	—	—	0.3	1.5	30				
Spectator areas	7.5	3.8	0.06	0.3	150			8	4
Swimming (pool and deck)	—	—	0.48	2.4	—	C			
Disco/dance floors	20	10	0.06	0.3	100			21	10.3
Health club/aerobics room	20	10	0.06	0.3	40			22	10.8
Health club/weight rooms	20	10	0.06	0.3	10			26	13
Bowling alley (seating)	10	5	0.12	0.6	40			13	6.5
Gambling casinos	7.5	3.8	0.18	0.9	120			9	4.6
Game arcades	7.5	3.8	0.18	0.9	20			17	8.3
Stages, studios	10	5	0.06	0.3	70	D		11	5.4

1. **Related Requirements:** The rates in this table are based on all other requirements of Standard 62-2001 (with addenda) being met.

2. **Smoking:** This table applies to non-smoking areas. Rates for smoking-permitted spaces must be determined using other means.

3. **Air Density:** Volumetric airflow rates are based on an air density of 1.2 kg/m<sup>3</sup> (0.075 lb<sub>m</sub>/ft<sup>3</sup>), which corresponds to dry air at a barometric pressure of 101.3 kPa (1 atm) and an air temperature of 21°C (70°F). Rates may be adjusted for actual density, but such adjustment is not required for compliance with this standard.

4. **Default Occupant Density:** The default occupant density shall be used when actual occupant density is not known.

5. **Default Combined Outdoor Air Rate (per person):** This rate is based on the default occupant density.

6. **Unlisted Occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

7. **Residential Facilities, Health Care Facilities, and Vehicles:** Rates shall be determined in accordance with Appendix E (of Standard 62-2001).

**Item-Specific Notes:**

A. For high school and college libraries, use values shown for Public Spaces—Libraries.

B. Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C. Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

D. Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.



Table D.2 - Minimum Ventilation Rates in Breathing Zone for Residential Buildings

Part A: Ventilation Air (cfm [L/s])					
Floor Area	0–1	2–3	4–5	6–7	>7
ft <sup>2</sup> (m <sup>2</sup> )	Bedroom	Bedrooms	Bedrooms	Bedrooms	Bedrooms
<1500 (<139)	30 (14)	45 (21)	60 (28)	75 (35)	90 (42)
1501–3000 (139.1–279)	45 (21)	60 (28)	75 (35)	90 (42)	105 (50)
3001–4500 (279.1–418)	60 (28)	75 (35)	90 (42)	105 (50)	120 (57)
4501–6000 (418.1–557)	75 (35)	90 (42)	105 (50)	120 (57)	135 (64)
6001–7500 (557.1–697)	90 (42)	105 (50)	120 (57)	135 (64)	150 (71)
>7500 (>697)	105 (50)	120 (57)	135 (64)	150 (71)	165 (78)
Part B: Exhaust Air					
If <b>continuous</b> —local ventilation exhaust air flow rates:					
Kitchen: 5 air changes per hour (based upon kitchen volume)					
Bathroom: 20 cfm [10 L/s]					
If <b>intermittent</b> —local ventilation exhaust air flow rates:					
Kitchen: 100 cfm (50 L/s) (vented range hood required if exhaust fan flow rate is less than 5 kitchen air changes per hour)					
Bathroom: 50 cfm (25 L/s)					

in a climate such as Canada's. Second, the oil crisis in the 1970's brought to realization the world's finite energy sources, producing a redirection toward energy-conserving designs. This, in turn, encouraged designers to limit the introduction of outdoor air that required cooling in summer and heating in winter. Third, a proliferation of chemicals in our environment has produced a vast array of potential air pollutants – from synthetic products permanently installed within buildings, to equipment used indoors, and even cleaning fluids used in maintenance. With more time spent in less fresh air and surrounded by more pollution sources, increasing numbers of buildings have had experiences with sick building syndrome (SBS). SBS (by one definition) is a situation wherein more than 20% of the occupants complain of symptoms such as headaches, upper respiratory irritation, and irritations of the eyes, among others that have become closely associated with SBS.<sup>3</sup> The presence of this syndrome is especially reinforced when it can be seen that occupants no longer experience the above symptoms during regular periods of absence (i.e. weekends).

Indoor air pollution can be described both in terms of the types of contaminants (gaseous, organic, or particulate) and the types of effects (odours, irritants, toxic substances) involved. People not only inhale contaminants, but also absorb and ingest some - the nose is not the only pollutant receptor/sensor. For some contaminants, such as asbestos and radon, the only method of avoidance is to design for their exclusion: they cannot be mechanically or otherwise removed after the fact, although increased ventilation can reduce their impact.

#### Distribution and Mixing of Air

Sufficient dilution of contaminants is especially important to achieving acceptable air quality. To accomplish this, the supply air must reach all occupied areas of the building, facilitating the mixing of fresh air into the existing air throughout each space. Mixing is stimulated by natural turbulence in the air and (in the case of mechanical ventilation) by the design of the air supply diffusers. Mixing ventilation is especially important when recirculation is used to provide thermal conditioning. If mixing is perfect, the pollutant concentration (and thermal conditioning) is uniform throughout the space. Furthermore, to rapidly mix the supply air throughout the room a diffuser helps prevent discomfort to the occupants.<sup>4</sup>

The design of the air diffuser can have a big affect on the speed, motion and direction of the outgoing air, which will

affect the overall efficiency and success of the system. Similarly the location of the diffuser may direct the strategy which the air is mixed. Supply air outlets which are placed at the top of a room will offer standard ventilation mixing, while the placement of the diffuser near the floor will facilitate such methods as displacement ventilation. For further explanation, see section D.8.

Likewise, the location of supply-air outlets is also very important for the comfort of the occupants. The goal is to gently circulate all of the air in a room so that there are neither stagnant nor drafty areas; revitalizing the air while properly maintaining the comfort of the space.

### Comfort Zones

Similarly, continually moving air is vital to the environmental comfort of a space. A cooling effect is experienced simply by the movement of air, both convecting away excess body heat and evaporating perspiration. It is this movement of air and not necessarily a temperature differential that accounts for the refreshing feeling that comes from a breeze.

Much of the comfort of a space is related to the experience of the internal environment. In most cases, especially in the extremely variable climate (dealing with very cold winters and very hot summers) of southern Ontario, Canada, the internal environment is significantly different from the surrounding outdoor microclimate for a good part of the year. As a result the control of the internal environment qualities must fall within a 'comfort zone'. That comfort zone is defined as a resultant balance between our bodies and their surrounding environment – made up of the interactions between the temperature, thermal radiation, humidity, air speed, personal activity level and clothing. Quantitatively, occupants in typical winter clothing prefer indoor temperatures between 20°C and 24°C. When dressed in summer clothes, they prefer 23°C to 26°C temperatures. Likewise, the comfortable RH (relative humidity) should be above 20 percent all year, below 60 percent in the summer and below 80 percent in the winter.<sup>5</sup> This ideal can be illustrated through the hatched area on the psychrometric chart seen in fig. D.02. As mentioned above, this comfort zone will change depending on changes in any ONE of these areas. Most relative to this discussion is to take note that an increase in air velocity will allow for an increase in both the RH and temperature levels; illustrated in fig. D.03.

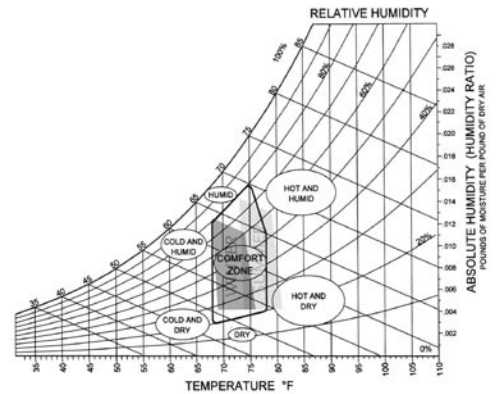


fig. D.02 - Psychrometric chart with the comfort zone and various types of discomfort experienced outside of that zone shown. The latest ASHRAE seasonal comfort zones are superimposed in different shades

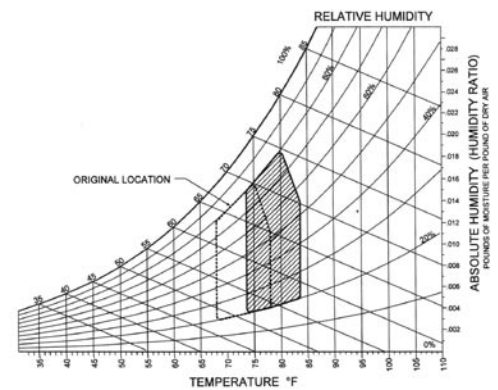


fig. D.03 - With high air velocity, the comfort zone shifts up to right - as noted by the hatched area.

As we realize the increasing cost of energy, this defined comfort zone is slightly expanding to alleviate the amount of input energy required to create the desired comfort zones – a degree or so colder in winter and a few degrees warmer in the summer. Unfortunately it is not as easy to alleviate the need for proper ventilation and air flow – we will always need a good supply of fresh air to feel comfortable within an interior space – therefore the significance of the design for air movement is again reinforced to be of utmost importance and its relationship to design based elements rather than mechanical solutions need to be implemented to also assist in alleviating a building's energy load.

## D.2

### Air as Design

#### Exterior Movement - Forms and Related Flows



fig. D.04 - Wind tunnel testing of a Mercedes-Benz E Class which is used to properly tune the aerodynamics of the body design.

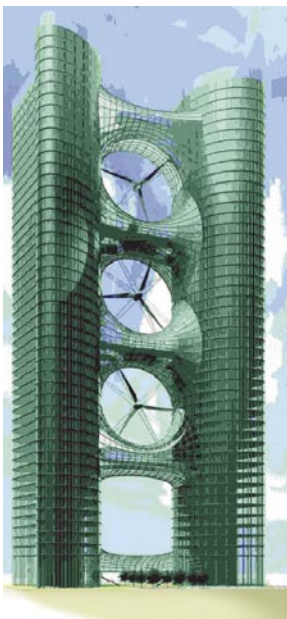


fig. D.05 - Design proposal from the research done by the Project WEB team.

The development of aerodynamics of buildings is not quite the art that one might observe when looking at the development and progress of say the automobile – the continual development of moving vehicles has always been to reduce the drag as they navigate the land, air or water. Since buildings are stationary they do not have to navigate in the same fashion as a moving object – instead it is the surrounding air/ wind which must navigate around the building. Therefore the direction of the windward force will change, along with the weather, making designing not as straightforward as that of a moving vehicle where the direction of the dominant wind force can be anticipated. With regard to building size, there are two factors to consider when dealing with air flow around a building. An increase in the size of the building directly influences the air movement around that building. As well, there is a natural occurrence for the velocity of air movement to increase as the distance from the ground increases. A taller building will be impacted by both factors.

The wind acting on a building will create pressures around it, create wind loads on the building, and resultant wind forces – such as gusting – will occur when the winds collide with the building. (Further details will be discussed in the section D.4) It is part of the design process to address these situations (horizontal loading, downward gusting, wind pressure pushes and pulls). The design strategy is usually concerned with resisting the forces of the wind, yet in other instances the design intent can also work with these ambient forces. The extent of most design is to simply design to withstand the wind forces, rightfully so, as the wind has potential to damage the building if not properly addressed, especially with cases of severe weather.

Unfortunately, wind design does not often further develop itself to design for capturing these forces, which could cup, cradle, direct or embrace the wind forces.

More recently as wind energies are once again being sought after, (for example the investment in large wind farms), architectural form is also taking an interest in accommodating these potential power sources. This approach is sometimes as dramatic as to incorporate wind turbines into the designs of the buildings – such as the Project WEB (Wind Energy for Built Environment) research headed up by the BDSP Partnership in the UK. The study is an example of catering exterior form to the direction and magnification of wind flow around a building to allow for the building's use.<sup>6</sup> fig. D.05. And a more substantial example, the proposed 69-story Pearl River Tower designed by Chicago's *Skidmore, Owings & Merrill* which is currently in development and is scheduled to be completed in 2009. Here the incorporation of wind turbines plays a crucial role in contributing to zero energy for the building. fig. D.06. Both projects use the building to channel air through its composite forms to increase the velocity (purposely creating gusting) and thereby creating more forceful air currents to power the turbines. This is known as the venturi effect, where the forms of the building collect the wind between them to increase the speed. These designs incorporate the wind to such a degree that they intentionally coerce the wind to purposefully create larger and more specific points of extreme wind pressures, to not only harness the ambient energies but to accentuate them.

More commonly, architectural form makes use of the pressures that are naturally induced on a building by the force of winds. Either simply by an organized and strategic use of fenestration (covered mentioned below under Interior Movement), by the use of wind cowls and/or stack chimneys or the strategic composure of building form to create the Bernoulli or venturi effect – all which are created with the use of purposeful architectural elements.

Such architectural design elements can be seen in the National Assembly for Wales, designed by Richard Rogers Partnership, which has multiple wind cowls to exhaust out much of the building at several different locations. The use and appearance of the wind cowls have been fully incorporated into the design, as these practical elements are a part of the design intention and success of the building. fig. D.07. They also work in conjunction with the stack effect in the building, which naturally occurs in all buildings – as hotter air will always rise above cooler air, creating an upward force (see sec D.3 for definition). The wind cowl, a cowl-shaped cap which turns with



fig. D.06 - Image of the proposed Pearl River Tower by SOM Architects - with blow up of intake design for the harnessing of wind.



fig. D.07 - Image of the recently finished National Assembly of Wales building by Richard Rogers Partnership.





fig. D.08 - Wind cowl atop the National Assembly of Wales building.

the wind, is used to improve the draft of a chimney or in this case a ventilating shaft, and makes use of Bernoulli's principle. (See fig. D.08 and also covered later in Sec. D.4) Although not part of the Richard Rogers' project, the opposite of a wind cowl, a wind scoop (or wind tower), which is a raised funnel (tower) used to force wind down into an opening and ventilate the area below, is another example of an architectural element which can assist in harnessing the forces of external air movement. Likewise, a design element that exploits the stack effect, a solar chimney, is used to increase internal air movement by raising temperature of the air within the chimney and thereby creating a greater temperature difference which will increase the speed of the exhausting air movement.

Overall the efficacy of building design and its relation to external air movement is still in its infancy. Although we know how to build to withstand the forces of wind, very few buildings make any use of these forces; and in a time when cheap energy becomes less abundant, there is a lot of room for progress in this matter. The thesis intends to look at what the resultant architecture will become if more of these ideas and designs are to be incorporated into architectural design.

#### Interior Movement – Mechanics and Related Spaces

As discussed above, interior air movement is a needed and desirable comfort quality of interior human environments. To accomplish this, some form of air movement must be accounted for and/or designed for within the layout, construction, or services of the built form. Not surprising, the smaller the building, the simpler the internal system of air movement is. Often passive means of air movement have been easily addressed when dealing with smaller interiors, yet, as mentioned above, the new forms of construction, which are better and tighter, do not necessarily allow for this to happen. As a result more design and initial development must be done for even the simplest of projects. This design development progresses in one of three ways: mechanical systems, passive systems or the combination of the two.

#### HVAC (Mechanical Systems)

Once a building project passes a certain size, the internal air flow is designed through the use of extensive mechanical systems. This is generally the way we have been designing for air movement in larger buildings for the last fifty plus years:

mechanically forced air systems, which contain fans and duct work to distribute the fresh air, often in combination with the heating and cooling system. The 'fresh' air is either mixed with the air already present in the enclosure to give 'mixing' or 'dilution' ventilation, or is used to displace air in the space to give 'displacement' or 'piston flow' ventilation.<sup>7</sup> Further information on the development of mechanical air handling will be examined in later sections in this appendix. Further information about ventilation will be covered in section A.8.

The use of mechanical systems has been a simple solution, which can be easily attached to or integrated into most designs, even though having a service which runs throughout a building can be tedious and a burden on space, as well as an eye sore if not well integrated. Often incorporated with the heating and cooling systems of the building the infrastructure can become quite large, yet these systems are able to address the entire building and, in an ideal situation, are seen as very controllable. But this system's success has been based on readily available cheap energy. As a result, the servicing of a building's mechanical systems is taxing both the efficiency and the economics of the building. As mentioned prior to this section, the need for efficient buildings and the general cost of energy is a growing concern; as a result the value of this design solution is beginning to fall.

This is not to say that mechanical systems do not have a place within the maintenance of the interior environment, especially in extreme circumstances, but that other solutions, possibly within the overall design of the cooperation of mechanical and other designed air movement strategies, may be the solution of tomorrow. This thesis will look at these possibilities and focus on the atrium to see what it means to design and its fruition.

#### Fenestration (Passive Systems)

The fenestration of a building – its exterior openings, such as windows, skylights, and clerestories – are the simplest of design strategies to strategically harness the air movement which is acting on and within a building. Therefore the placement and type of opening can be largely attributed to the success of tapping into the ambient energies to be used in ventilation.

Most schemes for this arrangement of ventilation use windows to control the volume, velocity and direction of airflow. For this reason, most types of windows are designed to be capable of being adjusted to varying degrees of openness.



fig. D.09 - Operable windows used in the Commerzbank building by Fosters + Partners, (left) open, (right) closed

Nevertheless, any operable aperture would work for the passage of air into a building. The transparency and configuration are not requirements; it is simply that windows have become the most common solution. Various patterns of fenestration and window operation have particular advantages and will be discussed in the following chapter.

Useful fenestration can be as simple as the cross ventilation of a single dwelling home or as complex as the Commerzbank office building in Frankfurt Germany. In a single dwelling home the opening of windows throughout the house will induce cross ventilation which is forced through the house as windward and leeward pressures act to create this drawing force. The Commerzbank office tower uses a similar concept but at a larger and more complex scale, which includes the use of stack effect. The office tower uses a triangular layout enabling a combination of interconnected atria and exposed sky gardens to naturally induce forces for capturing the pressures acting on the building and put them to work in its ventilation. By having each of the gardens face a different direction in the triangular plan the building is able to take advantage of windward conditions for at least one garden at any given time. See fig. D.09 and D.10.



fig. D.10 - A view inside one of the nine sky atria in the Commerzbank building as part of the passive ventilation system

It is through the appropriate design of fenestration that it is possible to successfully ventilate an interior space. Although the proper design of windows and ventilation openings may create an initial economical burden, this should be seen as an investment rather than simply an increased cost – as this designed environment will be able to ventilate without the added need for energy. The possibilities for elevating elements of fenestration and form from the purely aesthetic to practical components of effective design will be examined through this thesis. If these design considerations are more commonly introduced at the design stage, the implications may change the common perception of what constitutes successful attentive architecture, namely leading to the inclusion of passive ventilation techniques as a staple of good design.

#### Atrium Systems (Passive Systems and Hybrid Systems)

One of the approaches to air movement within buildings is to make use of atrium spaces. Along the same lines as fenestration, the introduction of the atrium into the passive ventilation system furthers the design of air movement. These atria will usually be open from ground level up to the upper levels where there will be exhaust vents for moving out the used air (these can also be in

the form of mechanically operated windows). The use of atrium spaces within a larger building is essential for collecting the air from multiple areas, some areas that may not have direct access to the exterior forces. The atrium space acts as a collector, either prior to or after the air has been consumed by the occupants. It creates a vertical “chimney” effects which have low intakes and high outlets to facilitate natural ventilation.

Unlike the fenestration system, the atrium system may also make use of mechanical methods to ensure the overall success of the system. Sometimes it is simply in the form of mechanically operated windows and/or a louver system to alter the air movement as the building monitor detects need for adjustment. More involved systems use electric fans to assist some of the movement, especially in obscure areas or spaces isolated from the passive system. In the case of climates such as Ontario, Canada, these systems are sometimes only successful in the milder transitional seasons (spring and fall). Nevertheless these methods are an increase in efficiency and relieve some of the energy load of running the building.

The inclusion of interior atrium spaces, which are pragmatically intended to make use of the ambient energies to reduce the running load of the building, are new elements in a post mechanical system architecture. That is not to say that the ‘atrium’ itself is a new element, in fact it has been around as long as definable architecture, but rather the recent reintroduction of the atrium as a staple of modern sustainable design.

In ancient Roman times, the atrium was the central open area of a house, but today the term atrium is more commonly associated with commercial or public buildings. The atrium space type could also include glazed courtyard spaces and multi-storied spaces. These atria are typically used as key architectural features in main entries, public circulation areas or as special destinations within a building – often a high traffic area. A typical quality of atrium design often involves skylights and generous glazing areas that provide an infusion of natural light, making them a prominent building area well suited to serve ceremonial and social functions. When properly designed, atria can be used as light courts that bring in day lighting into the depths of the building and utilize it to reduce energy use, provided that these atria are established with consideration for local climate specifications (an area that is already struggling to cope with excessive sunlight will not be aided by this device). Generally the atrium has been a program driven space, an element of the architectural cohesion of the design aesthetic, and not always that of a practical building element.

With the use of new understanding and technologies, both in methods and materials, and along with what was accomplished before mechanical ventilation, the atrium space has much to offer attentive architecture. It has a dynamic presence; it can work programmatically and pragmatically, and in doing so has many ramifications rooted in efficiency, economics, spatiality and experience. By examining local case studies, a discussion on the ramifications of different approaches will be completed through this thesis in an attempt to assess the viability and the opportunities for the inclusion of new ventilation methods - specifically the use of atria – and what it all means to architectural design.

## D.3

### Basic Air Flow Principles

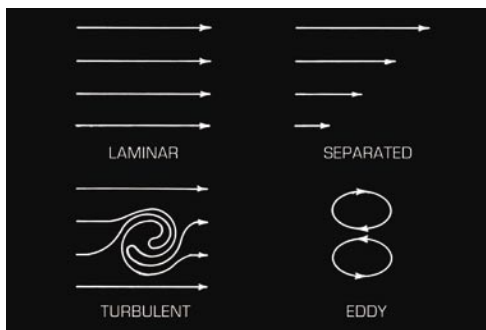


fig. D.11 - Diagram of the four types of air flow: laminar, separated, turbulent and eddy currents.

The way in which air moves, whether outside or within closed spaces, it can all be summed up in the following principles taken from Norbert Lechner's Heating, Cooling, Lighting: Design Methods for Architects<sup>8</sup>

*1. Reason for the air flow:* Air flows either because of natural convection currents, caused by differences in temperature, or because of differences in pressure.

*2. Types of Air Flow:* There are four types of air flow: laminar, separated, turbulent, and eddy currents. Air flow changes from laminar to turbulent when it encounters sharp obstructions, such as buildings. Eddy currents are circular air flows induced by laminar or turbulent air flows. See fig. D.11.

*3. Inertia:* Since air has some mass, moving air will tend to go in a straight line. When forced to change direction, air streams will follow curves and never right angles.

*4. Conservation of air:* Since air is neither created nor destroyed at the building site, the air approaching a building must equal the air leaving the building. Thus, lines representing air streams should be drawn continuous.

*5. High and low pressure areas:* As air hits the windward side of a building, it compresses and creates a positive pressure (+). At the same time, air is sucked away from the leeward side, thus creating a



negative pressure (-). Air deflected around the sides will generally also create a negative pressure. These pressure areas around the building determine how air flows through the building. Note: (i) pressures are not uniformly distributed (ii) type of pressure created over the roof depends on the slope of the roof (iii) these high and low pressure areas are not necessarily places of calm but also of air flow in the form of turbulence and eddy currents and can reverse the air flow in certain locations.

*6. Bernoulli effect:* The Bernoulli effect states that an increase in the velocity of a fluid decreases its static pressure. Because of this phenomenon, there is a negative pressure at the constriction of a venturi tube. See fig. D.12.

*7. Stack effect:* The stack effect can exhaust air from a building by the action of natural convection. The stack effect will exhaust air only if the indoor temperature difference between the two vertical openings is greater than the outdoor temperature difference between the same two openings. Note: (i) to maximize this basically weak effect, the openings should be as large and as far apart vertically as possible (ii) to allow air to flow freely from the lower to the high opening minimize obstructions.

Just as the initial forces of wind are created across changes in pressure, so too do these winds create changes of pressure onto objects that they cross. And it is through the manipulation of these characteristics that one is able to use the forces that are contained within air movement. Properly organized orientation, design and fenestration is how these manipulated forces will do the desired work for our internal environments.

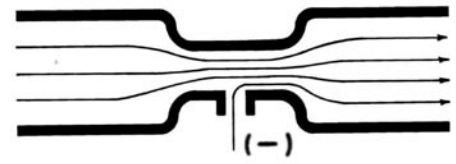


fig. D.12 - As the velocity of air increases, its static pressure decreases - The Bernoulli effect illustrated through a venturi tube

## D.4

## Wind Flow Principles



fig. D.13 - The force of wind seen blowing a row of trees

Most definitely the rawest form of air movement, and often appearing somewhat chaotic, wind operates based on principles to create its breezes, blowing and gusting. This motion can be in any direction, but in most cases the horizontal component of wind flow greatly exceeds the flow that occurs vertically. The speed of wind varies from calm to turbulent. See Table D.3 for the Beaufort Wind Scale, a descriptive system that determines wind speed by noting the effect of the wind on the environment – actual wind speed included.

Wind develops as a result of spatial differences in atmospheric pressure – pressures that are created from differences in heat. Generally, these differences occur because of uneven absorption of solar radiation at the Earth's surface. As a result, wind speed tends to be at its greatest during the daytime when the greatest spatial extremes in atmospheric temperature and pressure exist.

### Forces of the Atmosphere

There are 5 forces which act on the air within our atmosphere to create wind.

- pressure gradient force (real)
- coriolis effect (apparent)
- centrifugal effect (apparent)
- frictional force (real)
- gravity (real)<sup>9</sup>

Horizontally, at the Earth's surface wind always blows from areas of high pressure to areas of low pressure (vertically, winds move from areas of low pressure to areas of high pressure), usually at speeds determined by the rate of air pressure change between pressure centers. When expressed scientifically, pressure change over a unit distance is called pressure gradient force and the greater this force the faster the winds will blow. From the global perspective, colder air from the poles tends to sink and move towards the equator closer to the surface of the Earth. In contrast, warm air from the equator rises and moves towards the poles high in the atmosphere because it is lighter.<sup>10</sup>

The Coriolis Effect causes synoptic and global scale winds to swerve to the right of their initial direction in the North Hemisphere and to the left in the South Hemisphere. Instead of wind blowing directly from high to low pressure, the rotation of

Table D.3 - Beaufort Wind Scale

BEAUFORT NUMBER	DESCRIP- TIVE TERM	VELOCITY EQUIVALENT AT A STANDARD HEIGHT OF 10 METRES ABOVE OPEN FLAT GROUND				SPECIFICATIONS			Probable wave height* in metres	Probable wave height* in feet
		Mean velocity in knots	m s <sup>-1</sup>	km h <sup>-1</sup>	m.p.h.	Land	Sea	Coast		
0	Calm	< 1	0-0.2	< 1	< 1	Calm; smoke rises vertically	Sea like a mirror	Calm	—	—
1	Light air	1-3	0.3-1.5	1-5	1-3	Direction of wind shown by smoke drift but not by wind vanes	Ripples with the appearance of scales are formed, but without foam crests	Fishing smack just has steerage way	0.1 (0.1)	1/4 (1/4)
2	Light breeze	4-6	1.6-3.3	6-11	4-7	Wind felt on face; leaves rustle; ordinary vanes moved by wind	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break	Wind fills the sails of smacks which then travel at about 1-2 knots	0.2 (0.3)	1/2 (1)
3	Gentle breeze	7-10	3.4-5.4	12-19	8-12	Leaves and small twigs in constant motion; wind extends light flag	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	Smacks begin to careen and travel about 3-4 knots	0.6 (1)	2 (3)
4	Moderate breeze	11-16	5.5-7.9	20-28	13-18	Raises dust and loose paper; small branches are moved	Small waves, becoming longer; fairly frequent white horses	Good working breeze, smacks carry all canvas with good list	1 (1.5)	3 1/2 (5)
5	Fresh breeze	17-21	8.0-10.7	29-38	19-24	Small trees in leaf begin to sway; crested wavelets form on inland waters	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	Smacks shorten sail	2 (2.5)	6 (8 1/2)
6	Strong breeze	22-27	10.8-13.8	39-49	25-31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	Smacks have double reef in main-sail; care required when fishing	3 (4)	9 1/2 (13)
7	Near gale	28-33	13.9-17.1	50-61	32-38	Whole trees in motion; inconvenience felt when walking against wind	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	Smacks remain in harbour and those at sea lie to	4 (5.5)	13 1/2 (19)
8	Gale	34-40	17.2-20.7	62-74	39-46	Breaks twigs off trees; generally impedes progress	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind	All smacks make for harbour, if near	5.5 (7.5)	18 (25)
9	Strong gale	41-47	20.8-24.4	75-88	47-54	Slight structural damage occurs (chimney pots and slates removed)	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility	—	7 (10)	23 (32)
10	Storm	48-55	24.5-28.4	89-102	55-63	Seldom experienced inland; trees uprooted; considerable structural damage occurs	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes on a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected	—	9 (12.5)	29 (41)
11	Violent storm	56-63	28.5-32.6	103-117	64-72	Very rarely experienced; accompanied by wide-spread damage	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected	—	11.5 (16)	37 (52)
12	Hurricane	64 and over	32.7 and over	118 and over	73 and over	—	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	—	14 (—)	45 (—)

\* This table is only intended as a guide to show roughly what may be expected in the open sea, remote from land. It should never be used in the reverse way; i.e., for logging or reporting the state of the sea. In enclosed waters, or when near land, with an off-shore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

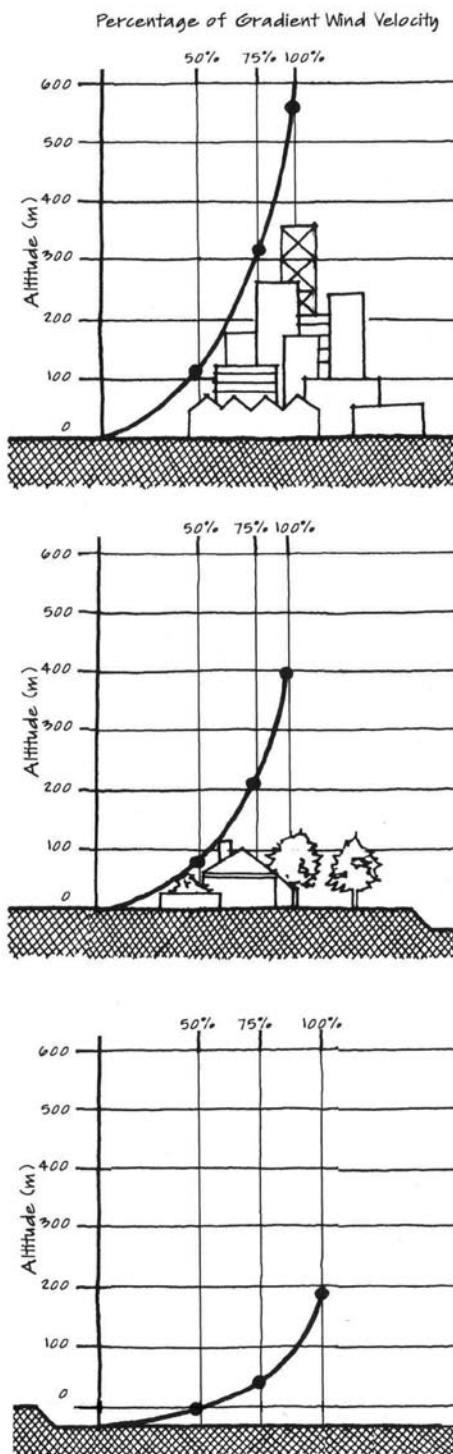


fig. D.14 - Effect of terrain on wind velocity profiles

the Earth causes wind to be deflected off course. The magnitude of the Coriolis force varies with the velocity and the latitude of the object. Coriolis force is absent at the equator, and its strength increases as one approaches either pole. Furthermore, an increase in wind speed also results in a stronger Coriolis force, and thus in greater deflection of the wind. But this force only acts on air when it has been sent into motion by pressure gradient force and will only influence wind direction and never wind speed.<sup>11</sup>

Centripetal acceleration is the third force that can act on moving air. It acts only on air that is flowing around centers of circulation. Centripetal acceleration is also another force that can influence the direction of wind. Centripetal acceleration creates a force directed at right angles to the flow of the wind and inwards towards the centers of rotation (e.g., low and high pressure centers). This force produces a circular pattern of flow around centers of high and low pressure.<sup>12</sup>

Friction deceleration is a force that can exert an influence on wind only after the air is in motion. Frictional drag acts in a direction opposite to the path of motion causing the moving air to decelerate. Frictional effects are limited to the lower one kilometre above the Earth's surface.<sup>13</sup>

And lastly, the force that continually affects all things on the planet, gravity. Gravity accelerates air downward but does not modify horizontal winds, as its force is of less significance to the overall flow of the wind.<sup>14</sup>

#### Localized Wind Movement

On a smaller scale wind movements can be created from certain specific geographical situations. These are mainly rooted in the first force mentioned above and occur at adjacent areas which have different absorption/ cooling rates from each other. The most common case is land that is beside a body of water.

On a warm sunny day along the coast, this differential heating of land and water leads to the development of local winds most commonly called sea breezes. As air above the land surface is heated by radiation from the sun, it expands and begins to rise, being lighter than the surrounding air. To replace the rising air, cooler air is drawn in from above the surface of the sea. Conversely, at night, the opposite occurs when the land cools faster than the sea. In this case, it is air above the warmer surface water that is heated and rises, pulling in air from the cooler land surface.<sup>15</sup>

## Wind and the Urban Environment

In an urban environment the presence of numerous obstacles significantly increases the irregularity of the ground as compared to rural environment and this in turn increases the effect of friction on the airflow. This becomes turbulences, as mentioned above, and occurs in the low atmospheric layers, and is generated by any ground obstacle as well as by thermal airflow instabilities. Turbulences decrease with increasing height, but this height would be higher in an urban setting than that of the rural environment.<sup>16</sup> This similar relationship can be found with the increase in wind velocity and height and is illustrated in fig. D.14.

Moderate to strong winds, which are approximately 20 m above the ground see a reduction of 20% to 30% in the average wind speed when moving from the countryside into the urban setting. Conversely, the turbulence intensity increases by 50% to 100%. With strong winds, the friction due to the city also creates a cyclonic rotation of the flow (up to 10°).<sup>17</sup>

Weak winds are 5% to 20% more frequent in a city than in the countryside. However, for wind velocities less than a threshold of 4 m/s, the wind velocity is higher in the centre than in the periphery of the city. This is attributed to the velocity created by the turbulence which is a result of the many obstacles the wind travels over/through.<sup>18</sup>

Furthermore, as the temperature increases when moving from the countryside into the city centre, this is related to the heat island effect. The heat island effect which is related to summer temperatures in urban areas being higher than in rural surroundings is mainly formed from two reasons, absorbed solar energy in building structures and the inability for the city fabric to properly radiate away its heat.<sup>19</sup> Thereby this affects the air so that it converges at the centre of the city under the effect of the pressure gradient induced by the horizontal temperature difference. Thus, the continuity of the flow creates an upward movement of air, which stops at a given height. The countryside breeze, which mainly blows in the late evening and the early morning, can reach 2 to 3 m/s.<sup>20</sup>

The urban environment is a complex study, in that it both inhibits and creates wind forces. Nevertheless the forces of air movement are present within our collections of built form and therefore the opportunity exists for us to develop exploitative systems using attentive architecture.



## D.5

## Wind Flow Around Buildings

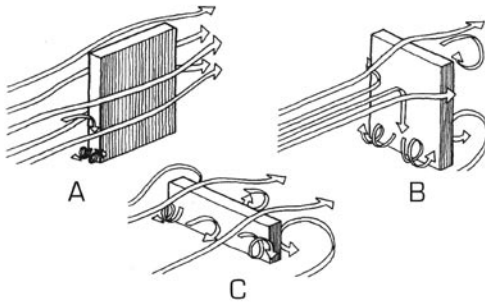


fig. D.15 - Wind patterns around single buildings

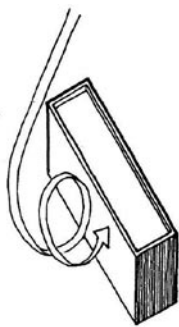


fig. D.16 - The 'Bar' effect on a single building

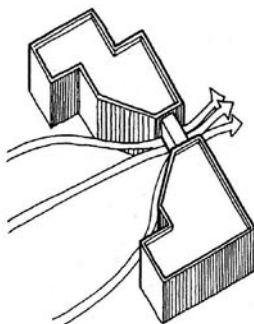


fig. D.17 - The 'Venturi' effect caused by two buildings which come together to form a tight passage

The principles of air flow are what characterize the movement of air, yet when these principles are applied onto an object or more specifically a building, the resultant becomes more complex. Much of the air that may have been at one point moving in a very laminar flow will soon be broken up, redirected or compressed when it comes in contact with buildings. From the exterior point of view the designer's concern is usually one of reducing the speed of the wind – to create inhabitable space (exterior or interior) and to create durable structures and skins for the building.

The generalized patterns of wind flow around thin windbreaks and thicker buildings help us to understand where shelter and increased airflows occur. These patterns become much more complicated than the basic air flow principles described in the previous section, as they are highly influenced by objects upstream, to the sides, and downstream of the wind-directing object being examined. The combination with neighbouring buildings further complicates things, which create local anomalies in wind flow that are unpredictable from these general principles.

Wind ultimately returns to its original flow pattern after encountering an obstacle such as a wind break or a building. Before it reaches the obstacle, it slows, builds (positive) pressure, and turns upward or sideways. As it passes the obstacle, it increases its speed, and reduced (negative) pressure results at the sides of and behind the obstacle. These pressure differences, flow patterns, and the size and shape of the wind-protected areas behind an obstacle are all usable for control of air motion, both inside a building and outside. Windbreaks are commonly used to protect outdoor areas; these can be fences or plants. Note that the densest windbreak produces the greatest reduction in wind speed behind it – but that the wind recovers its full velocity closer to such a barrier compared to a less dense windbreak. Thus, the denser the windbreak, the greater the reduction in wind speed but the smaller the area affected. Gaps in windbreaks can produce increased wind speeds through the gaps. Although a gap is a threat to winter wind protection, it is an opportunity for summer wind speed enhancement.<sup>21</sup>

Much study has been completed to better understand and predict wind patterns that will occur on our buildings. The following explanations and illustrations have been compiled by Stein and Reynolds in their Mechanical and Electrical Equipment

for Buildings to show wind behaviour to be expected in typical building combinations.

Tall buildings create particularly severe wind problems. Naturally wind velocities increase rapidly with height above the ground. Looking at fig. D.15 shows wind patterns around single buildings. (a) Tall, slender buildings; height greater than 2.5 times the width. (b) Tall, rather wide buildings; height between 2.5 and 0.6 times the width. (c) Long buildings; height less than 0.6 times the width.

With the bar effect which is illustrated in fig. D.16, the downward-spinning wind behind a building can reach 1.4 times the speed of the average wind.

With the Venturi effect seen in fig. D.17 and with few obstructions upwind or downwind from the narrow neck of a building, wind speeds through the neck can reach 1.3 times the average, up to heights of 100 ft (30 m), and 1.6 times the average at about 165 ft (50 m) in height.

The gap effect - fig. D.18, begins to occur with perpendicular winds and buildings of more than 5 stories (50 ft [15 m]) in height; by 7 stories, wind speeds 1.2 times the average can occur through the gaps; by 60 stories, gap wind speeds can be 1.5 times the average.

For higher buildings increased wind speeds occur at the corners (localized within a radius from the corner equal to the width of the building "d"); where height is 50 ft (15 m), wind speed can reach 1.2 times the average; for heights above 115 ft (35 m), wind speed can be 1.5 times the average. Where two towers approach each other, increased wind around corners and between the towers can go as high as 2.2 times the average for towers 330 ft (100 m) high. fig. D.19

At ground level, exceptionally strong wind currents are created by the rapid escape of air from the high-pressure windward side of the building to the low-pressure areas behind. This increased wind speed and turbulence within the wake of buildings pictured

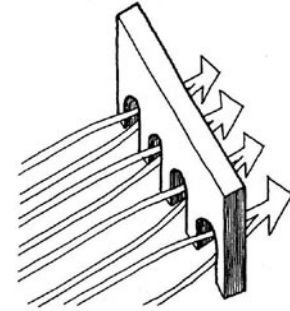


fig. D.18 - The 'Gap' effect

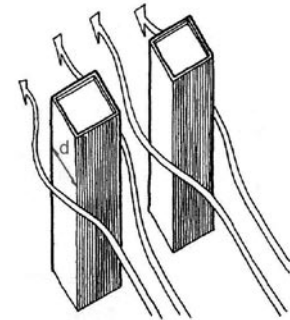


fig. D.19 - The 'Corner' effect which occurs on tall buildings at their corners as winds rush around them

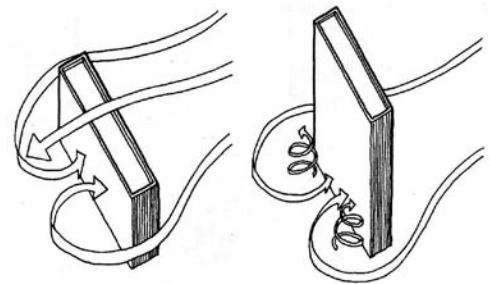


fig. D.20 - The 'Wake' effect which occurs close to the bottom on the leeward side of buildings

in fig. D.20 can be especially serious for towers at heights from 16 to 30 stories, where wind speeds can reach 1.4 to 2.2 times the average.

Commonly, the control of wind means utilizing wind-sheltered areas in winter while encouraging increased wind speeds in summer, with the remainder of thought spent on withstanding the burden of wind. But if further thought and investigation were given to how these winds are interacting with the buildings then there relationships could provide the basis for opportunities to work with the buildings.

## D.6

### Air Movement in Buildings



fig. D.21 - Diagram of a simple house layout outlining all the forms of domestic ventilation along with all the areas of infiltration (noted by coloured arrows) in and out of the building

The movement of air within a building works with the basic principles just as external air, with one exception; it remains tied to the external forces of the outdoor air acting on the building. Air can enter a building by means of infiltration and/or ventilation. Infiltration is an unintended influx of outdoor air due to air leakage through the building skin. Ventilation is a deliberate, designed introduction of outdoor air. Of the two means of air entry, infiltration is the more difficult to predict, since it is by definition unintended. Ventilation air quantities are intended and thus easily quantified. Although it is possible for infiltration and ventilation to occur simultaneously, usually it is reasonable to assume one of the following scenarios: only infiltration (which is typical of many smaller buildings with no ventilation) or only ventilation (typically required by code for larger buildings, and which usually pressurize a building to block infiltration). Both infiltration and ventilation airflow rates are expressed in litres per second (L/s).<sup>22</sup> Ultimately all air movement into and out of a building is related to pressure. The pressure exerted onto the building by the wind and the pressures within the building are a result of the external forces and/or mechanically created forces through electric fans. Further to wind forces are convection pressure forces, which are created by the different densities between warmer and cooler air. In conjunction with the pressure distribution around and within the building, other factors that determine the pattern of air flow are attributed to direction of air entering openings, the size, location, and details of said openings in combination with the arrangement of interior partitioning.<sup>23</sup>

The most effective approach to creating air flow within and through an enclosure is the use of cross ventilation. Using the pressure distribution on a building, the air flows from the strong positive pressure to the strong negative pressure areas

located on opposite walls. The extent of success depends on the direction of the outdoor air movement and its angle of impact on the building. The greatest pressure is what is sought after and is found in the centre of the wall being acted upon. Therefore the closer the openings are to the focal point, the greater the force behind the air movement.

Obviously, the maximum movement of air through a building is accomplished through the most forceful pressure coming into a space. This occurs when the wind is perpendicular to the incoming opening, and will be reduced to 50% as it reaches an oblique angle of 45°, although this still leaves a large range of incoming air to be useful.<sup>24</sup>

When air movement is occurring within a building, (although much slower than outdoors), some turbulence is ideal. Turbulence stirs up the air as it passes around a room rather than just passing straight through it.

The design of openings and/or the type of window greatly affects the amount and direction of air flow. As for the window type, single, double hung and sliding windows are great for allowing the air to enter unobstructed, but they open only half of what is glazed. Yet on double hung and sliding windows that opening can be on either top or bottom (left or right side) or a bit of both. On the other hand, casement windows not only open fully but they can direct the air flow (may or may not be desirable), as the sash acts as a fin wall (see below for further elaboration). For windows which offer some rain protection, awning and hopper windows deflect the rain while allowing the wind to pass by – unfortunately these windows obscure the wind and direct the flow upward as well as not being able to open all the way. See fig. D.22 for window types. So as each type has its advantages and disadvantages the choice of window should not be taken lightly during the design process. Further discussion about the design of the opening and surrounding elements is covered below.

The vertical placement of openings is directly related to its air movement intentions. Air movement intended for cooling and comfort usually has the openings about half a meter above the floor. Whereas high windows or ceiling vents are ideal for exhausting the hot air that collects near the ceiling. Often these higher, exhausting openings are out of reach for manual operation and need to be accommodated with automated operation.<sup>25</sup> This especially applies to atrium spaces that are used to passively ventilate enclosures. More elaboration will follow in future sections.

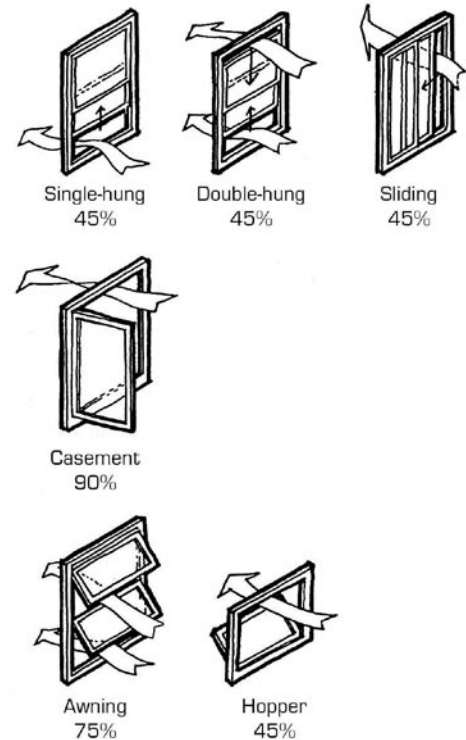


fig. D.22 - Window types with the percentage of openable area (average)

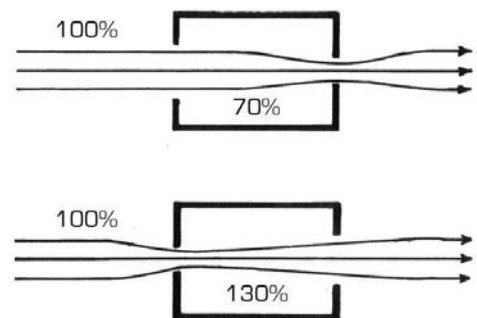


fig. D.23 - If the inlet is larger than the outlet the inner flow is slowed up and when the inlet is smaller than the outlet the inner flow is increased

Openings are interconnected to form a system where the amount of air flow is determined by the smallest size of the inlet and outlet openings. Ideally the inlet opening should be the larger of the two as it allows for the indoor air stream velocity to be maximized. This same arrangement can create interior velocities higher than the external wind force, even though the area affected is decreased by the smaller opening. See fig. D.23. Therefore the inlet opening determines the velocity as well as the air flow pattern, whereas the outlet opening has little effect on either.

### Air Flow Enhancements

The opportunity to design with the wind is made possible simply by adding or exploiting physical elements of the building to enhance the air flow through a building. This can be done in one of two ways; first internal design can allow for easy flow and/or use of vertical spaces to create flows using buoyancy strategies like stack effect. Secondly you can better manoeuvre the wind using fins, overhangs or specially designed roof vents.

The simplest approach to internal air flow is to have an 'open plan' design which easily allows movement throughout the enclosure. In the case of a single unit, multiple rooms can be connected by leaving the door open to cross ventilate. This works less well with an enclosure of multiple units where air movement can become stagnant when using external forces to cross ventilate. When different air pressures are not accessible to a single unit, unique solutions must be designed in order to maintain a flowing current. One such solution is the use of clearstory spaces above the multi-unit arrangement. See fig. D.24. This example begins to tap into the vertical element or stack effect which adds air buoyancy to the forces creating the flow. When designing vertical spaces, the intention is to allow the natural tendency for warm air to rise above the cooler air, and eventually out an opening at the top of the vertical space. A further exploitation of the stack effect is with the use of solar chimneys. Here air above a vertical space is deliberately heated to further increase the temperature difference and create a strong buoyancy effect out of the enclosure.

Fin walls are great elements that can direct the wind as they are able to change the pressure distribution on the effected wall. This is especially useful when trying to move air through a building using two openings on the same side. The optimum usage of fins is when the prevailing wind is passing at a 45° angle, redirecting the wind to be more perpendicular to the opening.



fig. D.24 - To cross ventilate in a double loaded corridor, a clearstory can be used to help move the air across

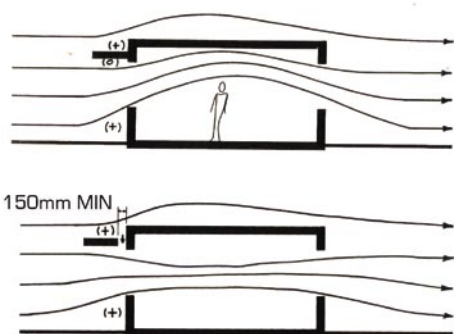


fig. D.25 - A gap in the overhang will allow the airstream to straighten out



Air flow through a building can be further directed and manipulated with overhangs above the window or opening. A horizontal overhang just above the window will cause the air stream to deflect up to the ceiling because the solid overhang prevents the positive pressure above it from balancing the positive pressure below the window. However, a louvered overhang, one with a 150 mm or greater gap or an overhang which is 300 mm above the opening will not effect the flow and will maintain its original course.<sup>26</sup> See fig. D.25

More common is the use of roof vents or ventilators. They are used to maintain attic temperature and when used on a larger scale enhance air flow in habitable spaces. The common wind turbine enhances ventilation about 30 percent over an open stack. When proper time is given to thoughtful design, it has been shown that ventilators can enhance the air flow by as much as 120 percent.<sup>27</sup> See fig. D.26 for examples.

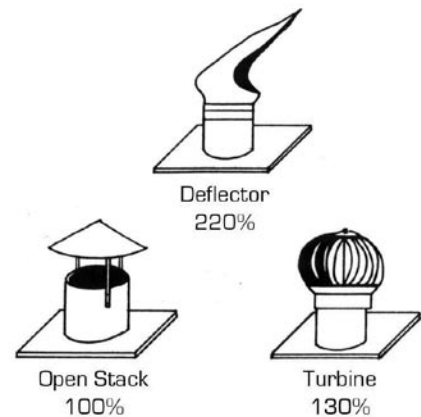


fig. D.26 - Each design for a roof ventilator has an effect on its performance

In areas where wind is hard to come by perhaps due to seasonal, no amount of attentive architecture can assist in capturing more wind. In this scenario, ventilation must be augmented with the use of fans. There are three basic ways motorized fans can be used to direct air movement. First, to exhaust hot, humid or polluted air; second, to draw air into a building – to add fresh air to the enclosure as well as for cooling; third to circulate the air within the building – which at a larger scale is combined with the overall HVAC system. See the following section on Mechanical Ventilation for further elaboration.

## An Overview of Ventilating Buildings

When man brought fire into his dwelling, he quickly discovered the need to have an opening in the roof to let out the smoke and at the same time to supply air to keep the fire burning. The North American native tepee is an example of such an innovation. Thus our first incentive for the ventilation of a space was to control combustion. The ancient Egyptians observed that stone carvers working indoors had a higher incidence of respiratory distress than those working outdoors. This was attributed to a higher level of dust in the indoor workspace. Thus, our second recognized need for ventilation was control of dust.<sup>28</sup>

With the crowding of people into cities, its effects soon made us aware that polluted air may be detrimental to health. The Greeks and Romans were aware of the adverse effects of polluted air in their cities and mines, as Hippocrates, 460– 377 BC stated in his writings that he associated air pollution with

## D.7

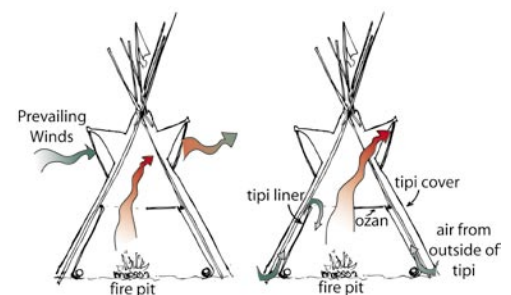


fig. D.27 - Sketches showing the North American Native People's tepee which used adjustable wind flaps oriented to catch the prevailing wind, allowing hot smoky air to be drawn out through the wind flaps and fresh outside air to be drawn in through the gap between the outer skin and inner lining of the tepee

the city.<sup>29</sup> Then in the Middle Ages, we began to realize that air within a building could somehow transmit disease among people in the crowded rooms. As well, the houses and buildings were heated with open fires in fireplaces. When air flow through the house was poor, smoke often spilled into the room and poisoned the air. Thus, our third reason to ventilate. King Charles I of England in 1600 decreed that no building should be built with a ceiling height of less than 10 ft (3 m), and that windows had to be higher than they were wide.<sup>30</sup> The objective was to improve smoke removal, and ultimately improve ventilation.

During the late eighteenth century, homes and buildings began the use of piped oil to fuel gasolier lamps indoor lighting. This added to the indoor air pollution as now the air needed to be cleansed of its worst and most persistent class of indoor pollutants: the waste products of combustion. Given the much greater heat load of flame light sources, and the atmospheric load of water vapour, carbon oxides and pure carbon which were generated did not help ventilation matters any.

Attempts to bring the existing illumination products within bounds varied, but were most concentrated on the area above the gasolier itself. The use of extract grills above the light-fitting was sometimes employed in practice (see below the Octagon House, Liverpool). It was a method both of disposing of sooty wastes and of exploiting the thermal surplus to convect foul air out from the heavily polluted zone immediately under the ceilings.<sup>31</sup>

It was around the late nineteenth century when literature began to appear concerning heating and ventilation. Although heating had been reduced to rule and formulae, ventilating had not been secured, and was still open to discussion – much of it sensitive, a lot more of it speculative. The early investigators of ventilation depended largely on the sense of smell as a guide to the ventilation of rooms. As industrialized societies fought their way out of the soot, smog and grosser pollutants of their atmosphere, they came up against a situation which clearly baffled most accustomed to a practical mechanical solution. Whereas temperature could be measured with relatively simple instruments and their causes identified, the ‘freshness’ or ‘stuffiness’ of air could not, largely because their causes could not be identified.<sup>32</sup> Consequently, research was done in the late nineteenth and early twentieth centuries to understand air quality, as ‘bad air’ was held responsible for the unpleasant sensations that were experienced in badly ventilated rooms.

Over the centuries, as we've closed in our houses and buildings to obtain an ideal thermal climate, it has in turn also limited the free movement of air. As a result, the ability to dilute pollutants has diminished. The environment within an enclosure is always more polluted from indoor sources such as humans, open fires (less of concern today, but still in many developing regions of the world) building materials, indoor activities, etc. than from outdoor air. This was and is the basis of the need for ventilation and for discussions on 'bad air', which is better known today as poor indoor air quality.

In addition, the demand for ventilation systems (incorporation) is now strongly linked to the evolution of legislation as it is a part of national building codes. In some European jurisdictions parts of legislation exist to mandate healthy indoor environments to promote occupant well being.<sup>33</sup>

### The Concept of Bad Air

The understanding of what constituted 'bad air' has been a long and multi-stage process – perhaps yet to be complete. By the early nineteenth century it was common knowledge that expired air was unfit for breathing until it had been refreshed (Wargentin, 1717– 1783). But identifying this process initially began with Priestley (1733–1804) who was first to conclude the existence of oxygen followed by von Scheele (1742–1786) and Lavoisier (1743– 1794) who concluded that air consisted of at least two gases. Using the knowledge of Mayow (1643–1678) that there was an exchange of air between the inhaled air and the body occurring within the lungs, Lavoisier (1781) pointed out the role of oxygen in breathing.<sup>34</sup> The work of Lavoisier was especially important for understanding the human metabolism, including the quantitative association between oxygen consumption and carbon dioxide (CO<sub>2</sub>) release. During the following half century it was accepted that the concentration of CO<sub>2</sub> was a measure of whether the air was fresh or stale. It was then further advocated that a correlation between diseases such as tuberculosis and its contraction in crowded places, known to be uncomfortable, was due to excessive heat or, in accordance with the view of Lavoisier, due to elevated concentrations of CO<sub>2</sub>.<sup>35</sup>

Upon becoming first professor in hygiene in Munich in 1853, Pettenkofer (1818–1901) further developed the concept of bad air. He noted that the unpleasant sensations of stale air were not due merely to warmth and humidity or to CO<sub>2</sub> and oxygen deficiency, but rather to the presence of trace quantities of organic material exhaled from the skin and the lungs. He

stated that “bad” indoor air did not make people sick, but that such air weakened the human resistance against agents causing illness. With Saeltzer (1872) and others, Pettenkofer’s view was that CO<sub>2</sub> was not important in itself, but was an indicator of the amount of other noxious substances produced by man. Pettenkofer and other researchers of this era often stated that source control is the best means to deal with CO<sub>2</sub> accumulation and an overall prerequisite for good hygiene.<sup>36</sup>

From where Pettenkofer left off, a number of studies were conducted between 1880 and 1930 in a search for evidence of the toxic effects of organic substances in expired air, then known as the ‘anthropotoxin theory’. No proof of toxic effects could be found (e.g., Brown-Se’guard & d’Arsonval, 1887) and since high concentrations of CO<sub>2</sub> as a single pollutant caused no discomfort. It was thought that the warmth of a crowded room together with odorous, but not toxic, bodily emissions were the main sources of discomfort in rooms with bad ventilation (Flygge, 1905; Hill, 1914). In 1905, Flygge wrote that the objection to an evil-smelling atmosphere was to be supported not on account of its poisonous properties, which had never been proven to exist, but on account of the resulting feeling of nausea. Thus at this point, ventilation was primarily a question of comfort and not of health.<sup>37</sup>

Very little research has been done since ventilation standards were set based on the assumption that man himself is the main source of indoor pollution – that being body odours. The more recent problems of radon in the late 1960s, formaldehyde in the early 1970s, house dust mites and SBS (Sick Building Syndrome) in the late 1970s, and now with the ever increasing health issues related to allergies, indoor air quality has again entered the scientific agenda. This current angle on indoor air quality, now well known by its acronym – IAQ, previously referred to in section D.1, has presented the fact that building materials, finishes and cleaners are affecting our air beyond our own uses and odours.<sup>38</sup> Today there is mounting evidence of the detriment of indoor air pollution, and thus the importance of ventilation from a public health perspective. And if we can not get rid of the contaminants, then our best means of dealing with them is a proper ventilation setup to dilute and/or remove the offending substances.

## Historically Dealing with the Air

Initially all that was required for needed ventilation – mainly for fires – was an arrangement of openings to allow air in and spent air out. As our enclosures became more complex, dealing with other problems, such as maintaining temperatures, avoiding draughts and running amenities such as gasolier lamps, they diminished and even restricted the act of ventilation.

Natural ventilation through operable windows was the primary means of ventilating buildings prior to the development of the electric power industry in the late nineteenth century. Before that, it was such innovations as the common high ceilings in buildings that were used to create a large volume of indoor air to dilute odours and carbon dioxide. Fresh air was provided by infiltration, the accidental leakage of air through cracks in the building, which along with operable windows created a steady exchange of air with the outdoors.<sup>39</sup>

As a result of ‘bad air’ problems and the overall lack of health within the cities during the nineteenth century, it was not the architects, but the medical doctors of that time which took drastic measures to address the problem. Medical practitioners, in the course of their normal rounds and as visitors accompanying inspectors of mines and factories, had unrivalled opportunities for observing the varieties of environmental disaster the nineteenth century had bred. They were be exposed to conditions that rarely came to the notice of architects. A few doctors went so far as to design the whole structure and use of the house anew, to remediate what they knew to be problems.<sup>40</sup>

A most famous example of pre-electrical fan ventilation systems was the Octagon built by Dr. John Hayward for his family in 1867, in Liverpool, England. The whole plan, section and construction of the house had been affected by his determination to control the ventilation, and everything including the gas-lighting, is consciously in place to realize this goal.

The basement was devoted principally to the collection and warming of the fresh air through hot water pipes. While up top beneath the roof ridge, was the foul air chamber into which all the spent air of all the rooms in the house was collected. From there it was drawn back down and out, powered by the waste heat from the ever burning kitchen fire. Although this set up was not totally uncommon, the Octagon was unique in the way all the principle rooms opened off of closed lobbies – which were connected vertically supplying air from the basement hot air chamber. See fig. D.28 + fig. D.29 In an elaborate system it

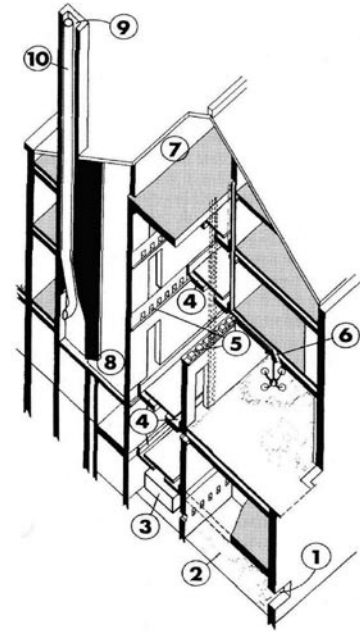


fig. D.28 - Axo of the Octagon House  
 1 Fresh air intake  
 2 Settling chamber in basement  
 3 Heating coils  
 4 Air passage in lobby floor  
 5 Air passage in cornice  
 6 Extract above gas lamp  
 7 Foul air chamber  
 8 Foul air down duct  
 9 Foul air chimney  
 10 Flue from kitchen range

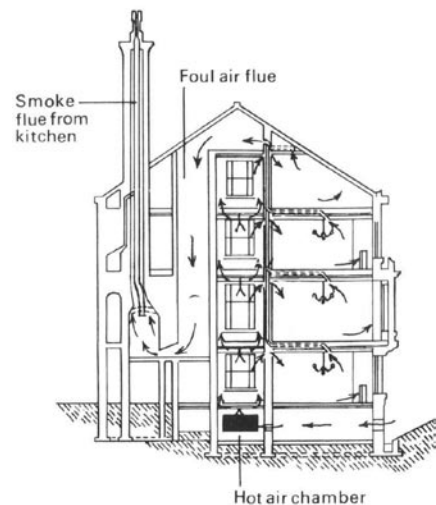


fig. D.29 - A section of the Octagon House showing the movement of air through the house



delivered fresh air to each of the rooms, as there were latticed openings at the top of the lobby corridors into each room which allowed the fresh warm air passage into each room. Now that each room was being supplied air, the spent air was taken out by a perforated ornament above the gasolier lamps. The air would then be piped through the ceiling, back into the walls between the room and lobby and released up in the foul air chamber through zinc tubing. Dr. Hayward was able to individually account for air movement in each of his rooms by the channelling and ducting of air passages throughout his house.<sup>41</sup>

The most drastic thing about the Octagon house is that the supply of fresh circulating warm air was not intended to heat the house, but there to prevent cold draughts which were associated with the supply of fresh air – the windows were sealed and each room was heated with its own fireplace.

The above example is a much more elaborate version of what eventually was developed – the hot air stoves and furnaces. These heaters brought with them an added benefit over and above heating – since it delivered the heat by means of air, and only when that air moved, it was inseparable from ventilation, or the ventilation had to be improved to the point where the hot air could move.<sup>42</sup> Consequently so began the development of ducts and spaces for vertical risers for heated air movement throughout the enclosure.

Although these systems allowed for better air movement, they depended on the heat of convection to move the air through the house, which was not very suitable for summer months – and again associated heating and ventilating with the same process. Ventilation's true success waited upon the developments of effective blower fans.

## Ventilation

## D.8

The motivation for and the need to ventilate our interior spaces has already been mentioned in previous sections. But the actual process of ventilation requires four major elements for it to happen, either mechanically or passively. In the book How Buildings Work, Edward Allen states that any building ventilation system, from the simplest to the most complicated, has four basic components:<sup>43</sup>

1. A source of air with acceptable temperature, moisture content, and cleanliness
2. A force to move the air through the inhabited space of the building
3. A means of controlling the volume, velocity, and direction of the airflow
4. A means of recycling or disposing of contaminated air

### Mechanical Ventilation

Mechanical ventilation makes use of electrically powered equipment to create and utilize the principles described above. Most mechanical systems continuously add a predetermined fraction of outside air and exhaust a similar fraction to the outdoors. Rather than relying on natural forces, fans are used to create a positive airflow. Ductwork running throughout the building is used to distribute the air by the push of the fans. Most mechanical setups are a combined HVAC (Heating Ventilating Air Conditioning) system. As a result, it can become impossible to separate heating cooling and ventilation. Therefore in these cases, it is unlikely to receive some fresh air without it being conditioned some way or another. See fig. D.31 for a simplified but typical mechanical ventilation setup. There are many different configurations of systems. Some of the main ones are:

**Local Exhaust Ventilation (LEV)** – This works on the basis of capturing a contaminant at source; an example would be a kitchen extractor hood ducted to outside. LEV is the most effective way of removing contaminants from a space and is widely used in industry where levels of hazardous emissions must be minimized. The air removed by the LEV is replaced either through infiltration or by a mechanical supply.<sup>44</sup>



fig. D.30 - Using metal duct work and diffusers has become the standard air distribution system through buildings.

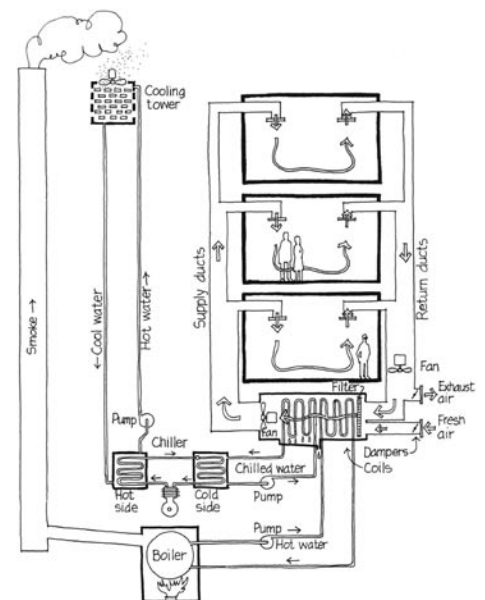


fig. D.31 - Simplified diagram of a typical mechanical system which incorporates ventilation amongst the heating and cooling operations

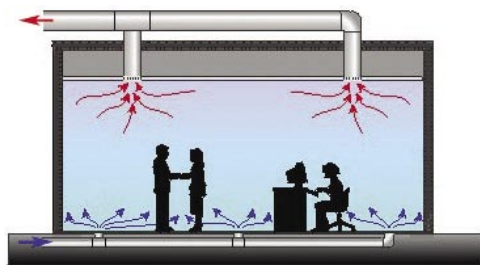


fig. D.32 - Simple diagram of displacement ventilation within a work space

**Mixing Ventilation** – Mixing ventilation requires that the room air and supply air are well mixed through the actions of incoming air momentum and buoyancy. This is the most widely used form of ventilation as it can be used for supplying both heating and cooling (air conditioning) as well as fresh air. The supply air is used to dilute the contaminants in the room and is often supplied at high level. With this type of ventilation system high contaminant levels can exist close to contaminant sources.<sup>45</sup>

**Piston Ventilation** – In this type of system there is a uni-directional flow of air (usually from ceiling to floor), where the supplied air propels the contaminated air out of the space, the room air being continuously swept by the momentum incoming air. This type of ventilation is often used in clean rooms where the supply air is passed through a (high efficiency particulate air) HEPA filter. Turbulence must be kept to a minimum to avoid contaminant dispersal.<sup>46</sup>

**Displacement Ventilation** – Displacement ventilation is an innovative concept for the supply of conditioned air and for the ventilation of buildings. Incoming air originates at floor level and rises to exhaust outlets at the ceiling to create an air distribution system. This system uses the natural buoyancy of warm air to provide improved ventilation and comfort. Relatively new to North America, displacement ventilation has been in use in the Scandinavian countries since the 1970s, where it is now seen as a proven technology.<sup>47</sup>

Incoming air is delivered to interior rooms by way of floor-level vents. The air moves at a low velocity and at a temperature only slightly below the desired room temperature. This incoming air displaces the upper air, which is exhausted through ceiling-level vents, to create a zone of fresh cool air at the occupied level. Heat and contaminants produced by activities in the space rise to the ceiling level where they are exhausted from the space. See fig. D.32 for a simple diagram of displacement ventilation.

Displacement ventilation systems are typically more energy efficient and quieter than conventional overhead systems. They also provide better ventilation efficiency, and thus improve indoor air quality.<sup>48</sup>

## Passive Ventilation

Ventilation that occurs without the added help of mechanical forces is considered passive. As mentioned earlier, passive ventilation was all we could do until the harnessing of

electricity. Natural ventilation relies on two effects to promote air movement: wind pressure and buoyancy. The most common form of natural ventilation is using operable windows. It is accomplished by utilizing wind as the source for air movement, with openings on the windward side of the building to control the intake of fresh air and openings on the leeward side of the building to control the exhaust of spent air. Windows and design enhancements (as discussed previously), controlled the volume, velocity, and direction of air flow. Other ventilation types include stack ventilation that uses buoyancy to induce air into the building at a low level and exhaust contaminated air at a high level. With passive ventilation, the ventilation remains separate from the heating and air conditioning so that further processes must be in place to complete the comfort of the enclosure. The separation of the processes within an environmental management system allows any one process to be adjusted without the implementation of the others. See fig. D.33 for a very simple passive ventilation strategy.

Unlike mechanical ventilation, natural ventilation is variable and cannot be used in deep plan buildings or buildings with very high heat gains. However, it has the advantages of not requiring fan power and creating a more natural environment when designed effectively.

#### The Shortcomings of Ventilation

The shortcomings of mechanical ventilation in our buildings are considered in the first chapter – where grounds are established for the return to and for contemporary development of passive ventilation. Their greatest limitation being abundant energy consumption, along with secondary concerns arising from attributed SBS, and space requirements for equipment that often adds poor aesthetics. It goes without saying that shortcomings exist for passive ventilation in our modern day. While they are not rooted in the shortcomings of mechanical ventilation, the challenges presented offer an opportunity for creative solutions. This is to say, that a proper awareness to attentive architecture can prepare a savvy designer to overcome these drawbacks in order to allow passive ventilation to be seen as a viable option.

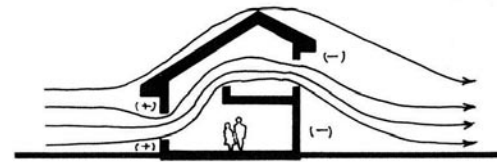


fig. D.33 - Simple design to take advantage of prevailing winds to passively move air

The key but not debilitating factor to remember to successfully designing passive systems is that ventilation is constrained by outdoor conditions. Factors such as noise, dirt, odours or other emissions from the streets are especially critical when operable windows are a significant element in the system – as they directly link the outdoors to the indoors (no mediator). In addition, passive systems need to have some approach to pre-condition the air to prevent cold drafts in cooler seasons, ultimately to deal with this indoor/ outdoor relationship.

## D.9

### Going Mechanical

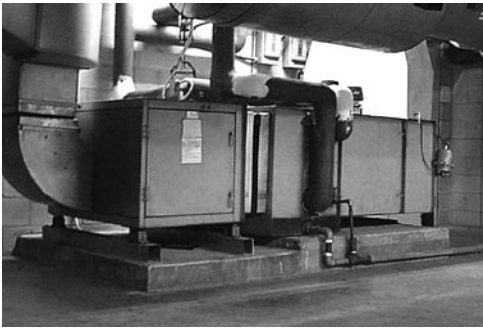


fig. D.34 - Just one example of many pieces of contemporary mechanical equipment used to heat, cool and move the air in our interior environments

It was not long after the industrial revolution that the history of environmental management changed. We began to rely on 'regenerative' solutions, whereby energy was consumed to manage our enclosures. Prior to, 'conservative' and 'selective' set ups were used which cooperated with the natural surroundings to collect and use the forces in nature to accommodate us. These regenerative developments were especially predominant in North America where an abundance of energy could be found.

Although domestic ventilation was not going to flourish until the full development of the electric fan, much of its development began even before the domesticity of electricity. Shortly after 1860 fan forced ventilation began to flourish. The pressing needs of mining and shipping, and of industrial processing (such as the drying of tea, for which Davidson developed his Sirocco fans) and the increasing size and complexity of buildings all provided powerful stimuli to invention. The steam engine, and later the slow running gas engine drawing on the common town gas mains, provided the power to run the fans. By 1870, the B.F. Sturtevant Company patented a steam-coils-plus-centrifugal fan combination that was well beyond the development stage. Unfortunately the size and weight of such equipment often made its location within a building difficult. Consequently more often than not it was then placed out of the way and depended on ducting to push and pull air all over the building. This led to criticism which found this means to be a 'roundabout and unscientific mode of ventilation'.<sup>49</sup>

The progressive application of fans was held back until the last years of the century, by two major obstacles. The first was a lack of aerodynamic knowledge, and the other was the lack of a small power source adaptable to fans of domestic or personal scale. The former was resolved over time by the practical experiences of companies like Sturtevant and Sirocco and by the design work of Rateau in France (the inventor of



the modern high-speed centrifugal fan) and the theories of Joukovsky in Russia (the intellectual parent of axial flow fans). While with the sudden simultaneous breakthroughs of the development of domestic electrification and of Nikola Tesla's alternating current motor, the latter obstacle was overcome as well.<sup>50</sup> In fact the revolution of all environmental technology was consummated in 1882, the year of the domestication of electrical power, an achievement that confirmed developing environmental advances, and laid the essential foundation for more sophisticated ones.<sup>51</sup>

The 1880's contain the first mentions of electric fans as room coolers in downtown New York. The relative smallness in size and its ability to be in the room it was ventilating instantly created its popularity. Nothing had compared to its great handiness for its management and location. It was upon these bases that the growing sophistication of ventilating techniques in the twentieth century was to be built.

Therefore, it was not until electric power became generally available early in the twentieth century that the desired ventilating rates and temperature control could be achieved so aggressively. As late as 1920, the relative location of open windows and room exhausts were still studied.<sup>52</sup> But along with further developments of regenerative designs rather than those of conservative or selective innovations, the studies were soon given up. The expansion of air conditioning in the 1930's made natural ventilation obsolete, as everything became sealed up to contain the desired 'environment'.

Until recently, this regenerative model for air movement had not been questioned. As energy becomes more expensive and less available, and as unsatisfactory conditions from mechanical environments continually emerge with such situations as SBS, questions beg to be asked. Even with more complex computer controls and energy efficient designs alternatives must be considered. The potential exists to return to passive methods or hybrid systems to obtain a reliable and sustainable solution – looking to attentive architecture and natural forces and characteristics to make our designs more efficient.

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## Endnotes

- <sup>1</sup> Richard Kadulski, *Residential Ventilation : Achieving Indoor Air Quality* (North Vancouver, BC: Drawing-Room Graphic Services, 1988), 24.
- <sup>2</sup> Benjamin Stein, *Mechanical and Electrical Equipment for Buildings*, 10th ed. (Hoboken, N.J.: Wiley, 2006), 1597-1600.
- <sup>3</sup> *ibid.*, 112
- <sup>4</sup> AIVC - Air Infiltration and Ventilation Centre, "How does Ventilation Work?" <http://www.aivc.org/frameset/frameset.html?./Faq/faq2.html~mainFrame> (18 December 2006).
- <sup>5</sup> Norbert Lechner, *Heating, Cooling, Lighting : Design Methods for Architects*, 2nd ed. (New York ; Chichester England: John Wiley, 2001), 62.
- <sup>6</sup> N. S. Campbell and eds Stankovic, "Wind Energy for the Built Environment: Project WEB," (2001), 25.
- <sup>7</sup> AIVC - Air Infiltration and Ventilation Centre, *How does Ventilation Work?*.
- <sup>8</sup> Lechner, *Heating, Cooling, Lighting : Design Methods for Architects*, 2nd ed., 255.
- <sup>9</sup> University of Nebraska Omaha, "Cartography and Geographic Information Systems Laboratory - Wind Principles," <http://maps.unomaha.edu/Peake/3510/windprinciples.htm> (18 July 2006).
- <sup>10</sup> PhysicalGeography.net and Fundamentals of Physical Geography, "7(n) Forces Acting to Create Wind - Chapter 7," <http://www.physicalgeography.net/fundamentals/7n.html> (20 July 2006).
- <sup>11</sup> *ibid.*
- <sup>12</sup> *ibid.*
- <sup>13</sup> *ibid.*
- <sup>14</sup> University of Nebraska Omaha, *Cartography and Geographic Information Systems Laboratory - Wind Principles*
- <sup>15</sup> The Weather Doctor, "Weather Elements: Sea and Land Breezes," <http://www.islandnet.com/~see/weather/elements/seabrz.htm> (18 July 2006).
- <sup>16</sup> M. Santamouris and others, *Natural Ventilation in Buildings : A Design Handbook* (London: James and James Science Publishers Ltd., 1998), 22.
- <sup>17</sup> *ibid.*, 22
- <sup>18</sup> *ibid.*, 22
- <sup>19</sup> *ibid.*, 23
- <sup>20</sup> *ibid.*, 22
- <sup>21</sup> Stein, *Mechanical and Electrical Equipment for Buildings*, 10th ed., 69-72.

- 22 *ibid.*, 116.
- 23 Norbert Lechner, *Heating, Cooling, Lighting : Design Methods for Architects*, 2nd ed., 259.
- 24 *ibid.*, 259
- 25 *ibid.*, 262
- 26 *ibid.*, 261
- 27 *ibid.*, 263
- 28 Joseph A. Wilkes and Robert T. Packard, *Encyclopedia of Architecture : Design, Engineering & Construction* (New York ; Toronto: Wiley, 1988).
- 29 J. Sundell, "On the History of Indoor Air Quality and Health," *Indoor Air* 14 Suppl 7 (2004), 52.
- 30 John E. Janssen, "The History of Ventilation and Temperature Control," *ASHRAE Journal* 41, no. 10 (October, 1999), 47.1
- 31 Reyner Banham, *Architecture of the Well-Tempered Environment*, 2nd ed. (Chicago: University of Chicago Press, 1984), 56.56
- 32 *ibid.*, 40
- 33 World Health Organization, "Housing and Health Regulations in Europe - Final Report July 2006," <http://www.euro.who.int/document/e89278.pdf> (18 August 2006).
- 34 Sundell, *On the History of Indoor Air Quality and Health*, 52
- 35 *ibid.*, 52
- 36 *ibid.*, 54.
- 37 *ibid.*, 56
- 38 *ibid.*, 57
- 39 Corky Binggeli, *Building Systems for Interior Designers* (Hoboken, N.J.: J. Wiley & Sons, 2003), 139.
- 40 Banham, *Architecture of the Well-Tempered Environment*, 34
- 41 *ibid.*, 38
- 42 *ibid.*, 49
- 43 Edward Allen, *How Buildings Work : The Natural Order of Architecture*, 2nd ed. (New York: Oxford University Press, 1995), 90.
- 44 University of Strathclyde, "ESRU Home Page - Institute for Energy and Environment - Ventilation," <http://www.esru.strath.ac.uk/> (18 December 2006).
- 45 *ibid.*
- 46 *ibid.*
- 47 R. T. Tambllyn and Advanced Building Technologies and Practices, "Ventilation & Air Quality - Displacement Ventilation," [http://www.advancedbuildings.org/main\\_t\\_vent\\_displ\\_vent.htm](http://www.advancedbuildings.org/main_t_vent_displ_vent.htm) (18 December 2006).

<sup>48</sup> Christopher R. Schaffner, "The Green Engineer - Displacement Ventilation," <http://www.greenengineer.com/ideas/dv.htm> (18 December 2006).

<sup>49</sup> Banham, *Architecture of the Well-Tempered Environment*, 2nd ed., 52.

<sup>50</sup> *ibid.*, 52

<sup>51</sup> *ibid.*, 25

<sup>52</sup> Janssen, *The History of Ventilation and Temperature Control*, 47.

## **Appendix E :: Designing for Air Movement**

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During the course of this thesis, different opportunities were taken to explore, play and understand the realities of air flow and design. By illustrating with installations and investigating the industry tools and services, an appreciation and understanding of the factors designers must deal with is examined. This appendix documents the different approaches examined, their development and their benefit, complementing the thesis investigation to better understand passive air movement strategies used in building design.

## Identifying Flow

## E.1

When first developing the architectural thesis, a series of installations were completed to stimulate ideas. One such installation revolved around the concept of identifying the interaction of flow across objects. This series of explorations became known as 'Give + Take' and was not a final destination as much as part of the ongoing development of the thesis focus. It stemmed from two initial themes, the force of the land and the opposing forces acting back against it.

*Give + Take* indulges the ideas of collision, negotiation, and resolve within the context of the natural forces acting on the land. In an attempt to better understand the dialogue of two opposing forces, a process of visualization and modeling were executed to illustrate the negotiation between the two. Beginning with a series of mappings to investigate form and flow, (see fig. E.02 – E.04) the process then continued to develop into an installation piece of hung fabrics. By placing the observer within the hung fabric to negotiate a path, the observer became part of the inter-relationship to develop a



fig. E.01 - Sand picked up by the wind flows over the dune which was formed by similar forces.

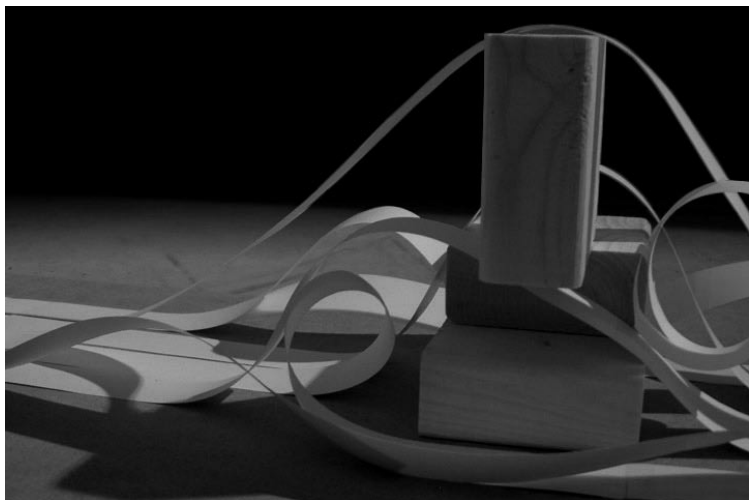
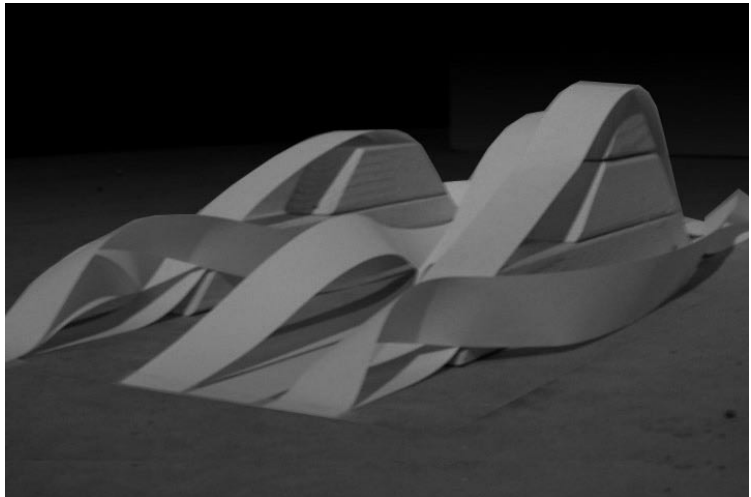
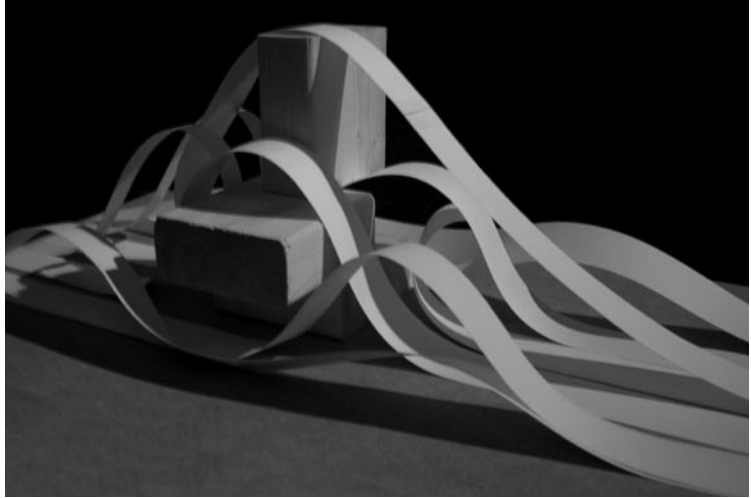


fig. E.02 + E.03 + E.04 - Paper strip and wood block modeling to visualize and articulate flow over form. Works done by author.

greater discourse about the mechanics, play, and balance of the forces acting on one another. See images of fabric installation in fig. E.07 – ED.10.

#### Result: Imagery, Visualization

Rudimentary as it was, this exercise created imagery and visual relationships as it attempted to illustrate fluid movement. Drawing from the abstraction of design, this installation and others like it are only the beginning for designing with air movements – opening the gateway to thinking about flow. To visualize this dialogue, ideas about the mapping of fluid dynamics were examined to begin creating successful imagery. See fig. E.01 + E.05. Likewise, through this idea of balance, a relationship is encountered; one of give and take. From the work, a heightened awareness of form and flow is brought to the observer. The designer begins to think about how fluids flow, their corresponding form, and the relationship of that fluidic form to the form of the objects they flow over.

Many thoughts arose about the relationship between the solid and fluidic, and to demonstrate this, materials were used to reflect those characteristics. Although many viable possibilities existed, flowing materials such as strips of paper and cotton fabric were used to develop the fluidic notions; simple solids, such as wood blocks were selected to formalize the ideas of solidity. This process often tapped into another useful concept: that of negative space. Negative space refers to that which is not present or in this case, not easily observed; such as the winds that act on the mountains.

Although the end product of the installation was a showcase of images which originally focused on the relationship between the energies of the land and other forces acting on it – its value lay in what it could offer the student and designer when contemplating air flow design. In an attempt to visualize this balance, the still models and walk through fabrics portrayed fluidic motion in its struggle to navigate fixed objects. A visual perception of force and its resulting influence was demonstrated. What is more, this process and product helped address the difficulty of showing and grasping these movements in three dimensions. Thinking with the third dimension is quite often difficult when working on two dimensional drawings. The design process and documentation tend to work in only two dimensions which can oversimplify the situation, especially when documenting air movement. This motion, on paper, is reduced to ‘magic arrows’. See fig. E.06. They literally represent the movement of air through a drafted project often using

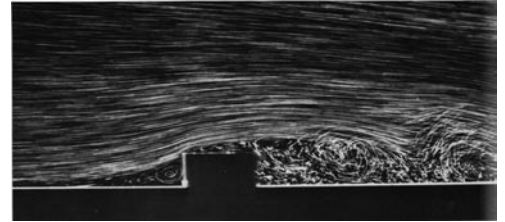


fig. E.05 - Dyes placed in a water flume show the turbulent separation caused by flowing over the rectangular block.

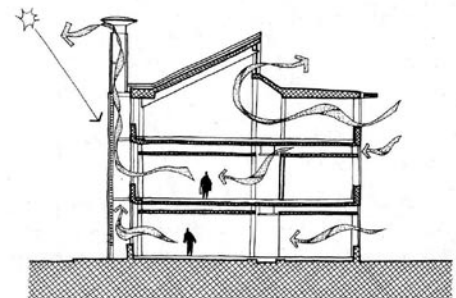


fig. E.06 - Section through the BRE office building in Garston, UK, showing the movement of air with “Magic Arrows”

fig.E.07 - Hung fabric installation view from above.



fig. E.08 + E.09 - Activated fabric installation caused by observer's push and pull on fabric and air as they walk through.



fig. E.10 - Entry view into installation.





red and blue arrows, indicating hot and cool air respectively. The seemingly clear picture such a diagram gives does not in fact accurately translate the complexity of movement in three dimensions through a volume.

The student and designer can use this installation exercise as the starting point to understand the flow and movement of air as well as perceiving negative space and working three dimensionally. The exercise inspires the student to carefully attend to form from flow, and creates a stepping stone to move into details related to the mechanics of air movement. Overall, the exercise expands the student's interests and knowledge, all of which is strategic to encourage deliberate designing for managing air flow and ultimately to the success of attentive architecture.

## Smoke Box Testing

## E.2

The completed work as outlined in section E.1 led to further ideas for experiencing and communicating the air movement theme. These ideas became known as 'Smoke Box' testing which was developed into a design exercise which was eventually used in the undergraduate curriculum.

### Development

From the aforementioned visualization installation, the follow up question became, how could this be done to test design models? The goal then would be to study the relationship of airflow in and around the design using a tactile and performance based visualization methodology. Perhaps even some of the primary air movement concepts, which are taught in course lectures and textbooks, could be demonstrated. It would be accomplished with hands-on modeling and testing in three dimensional situations. To complete the process, photo documentation would be required to record what happened and to examine the process across time. The ability to utilize time lapse photography would be helpful to slow down the movement and to understand these airflow dynamics. Overall, the intention of the exercise was to offer the student and designer an opportunity for exploration into the understanding and manipulation of airflow. Although before anything could be tested or communicated the overall methodology needed to be formed. With the assistance of three undergrad architecture students, this methodology was to be worked out.<sup>1</sup>

The initial task then, was to create an air flow of neutral buoyancy that would move through or around objects and



fig. E.11 - Smoke Box development with undergraduate students Krista Duynisveld and Sue Chen along with Professor Terri Meyer Boake

interiors to gauge the quality of air movement. The air flow would need to be visible to the observer. Several techniques were tried and compared before arriving at the final method. Initially dry ice was blown against the model. The disadvantages were that the smoke was a stream of cold air that sank making it difficult to maintain a laminar stream into the test objects. Next, combustible materials were set to smoulder to produce smoke. But this methodology could only be used outdoors, which added other problems like controlling the direction of the smoke. The test method arrived at was to guide artificial fog through a tube into a transparent flow tunnel to create a fairly even laminar stream for testing. See fig. E.14 for a diagram of the setup.

Smoke made by a theatrical fog machine, was sent through the 'box' design with the directional assistance of a large cone. This cone focused the air and allowed the tester to direct the air into openings, onto façades, at angles etc. A large box fan sat on the other side of the 'box' in order to suck the smoke across and through. The fan also dissipated the smoke and with the assistance of the ventilation in the shop, cleared it out. Meanwhile someone documented the smoke movement within the box with the use of a video and/or digital camera.



fig. E.12 - Undergraduate students preparing their 'Smoke Box' models for testing.

#### Result: Ideas, Application

The outcome of the proposed design exercise, is a tech-based creative design process – simple enough to introduce to an inexperienced audience and not overly cumbersome to put together and run. The overall benefits of producing such an exploration can help the experimenting designer in many ways. Initially, the exercise is a vital teaching aid as it helps to visualize the movement of air within the confines of an area, as the smoke is seen moving around and through the models. As a result of increasing the visualization of the air, a better comprehension and understanding is developed in the student's mind as this hands-on experience compliments the theory and drawings of what is taught in lectures. Secondly, the added benefit of working with hands-on projects gives the ability to study the movement in 3-dimensions, and goes beyond the illustration of arrow diagrams. Furthermore this process is a simple means of testing ongoing designs and simulating proposed strategies in building air movement, eventually opening the door for related experimentation. This process and product give the student the opportunity to investigate, to understand the methodology to do such, and to gain the awareness of how air reacts with built forms. The feasibility of this process was tested by first



fig. E.13 - Undergraduate students examining their 'Smoke Box' models while using the testing setup.

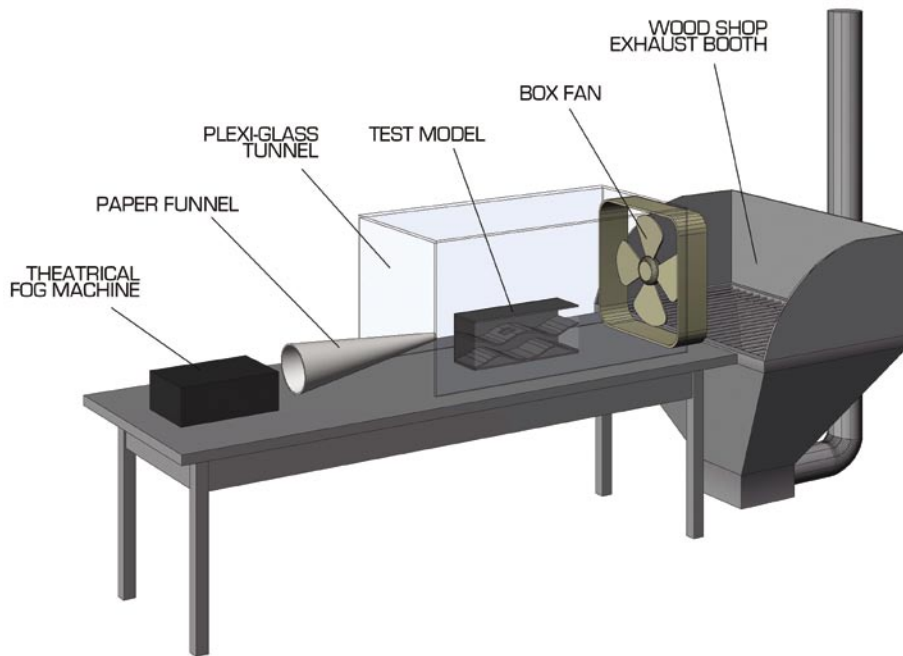


fig. E.14 - Diagram of 'Smoke Box' testing setup.

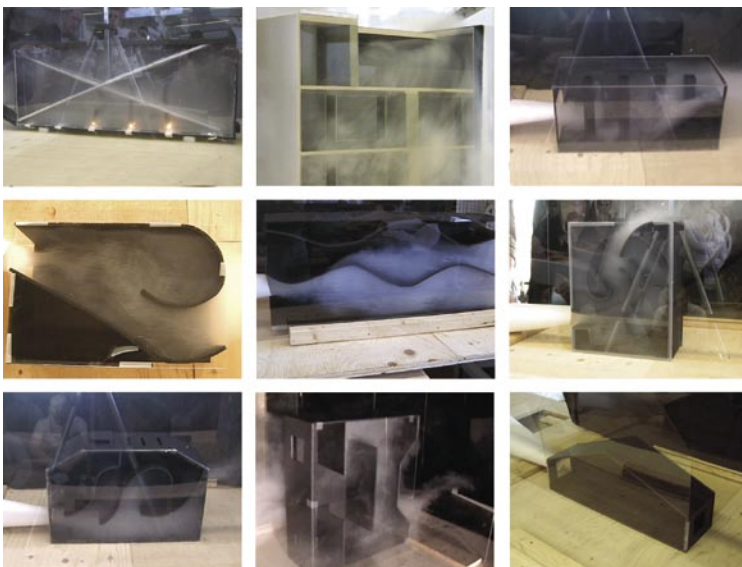


fig. E.15 - Different examples of 'Smoke Box' models used by the undergraduate class.

year undergraduate students as a unique design experience in conjunction with ARCH 125 – Principles of Environmental Design. See fig. E.12 + E.13 + E.15 for images. The research resulted in a process to document visualizations of airflow rather than using proposed airflow diagrams (magic arrows – see fig. E.06 for example). This process can lend itself to be used within the curriculum.

For the seasoned designer (practitioner), something this fundamental may not be the final tool needed to successfully test their design intentions. However it could help in developing ideas and basic strategies, just as with the installations spoken about in section E.1. Likewise this simple methodology and setup also goes to illustrate how simple it is for anyone to test the fundamentals of a design. Nevertheless, this exercise is best suited for students, while practitioners would further and better benefit from the tools addressed in the remainder of this chapter.

In regards to the thesis, the development of the smoke box methodology in itself was a gateway into the trials of demonstrating air movement. Dealing consecutively with the invisibility of air movement and then the intent to design with it, was most challenging. Designing with air flow in mind is harder than you think. Realizing the challenge itself, was most constructive to the thesis development. It contributes good commentary to the discussion about the success of this kind of designing for the future of attentive architecture. The exercise greatly enhances the realization of challenges and obstacles and should greatly assist the development of air flow in real life design situations.

## E.3

### Computer Models

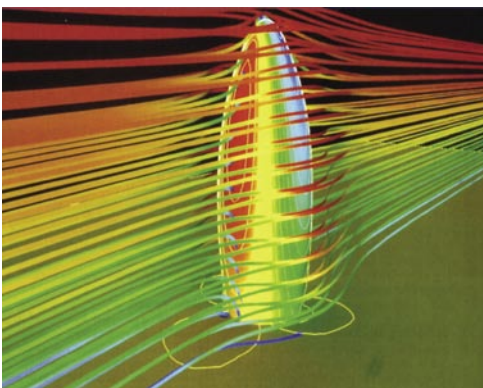


fig. E.16 - Example of CFD modeling which was used in the development of Norman Foster's Swiss-Re Tower in London, UK.

Beyond the tangible settings and tools of scale models lies the realm of the virtual. Computers are part of every aspect of today's world, and the exploration for the thesis should be no exception.

#### Overview

Computational fluid dynamics (CFD) is the use of computers to analyze problems in fluid dynamics – air is such a fluid. The past 25 years have seen CFD become an integral part of the engineering design and analysis environment. With CFD, users can simulate fluid-flow and heat-transfer phenomena in a design, and understand how that design will perform before they decide whether to use it for construction. The savings that



can be realized are obvious: fewer iterations to the final design, shorter lead times, fewer expensive prototypes to produce, and so on. On top of this, CFD provides a cost-effective means of testing novel designs and concepts that would otherwise be too expensive and risky to investigate.<sup>2</sup>

From the very simple program (for architects and designers) to the very complex ones (used by engineering specialists), the CFD programs can assist with varying degrees in the calculation and quantification of air flow throughout and around a design.

### The AIOLOS Software

During this thesis a basic program called AIOLOS was sampled to evaluate the potential for using in a design situation for air flow. The format of this program does not use a virtual model to do its calculations, as may be the case with a more complex program used by a specialist (see next section). AIOLOS uses only an 'input' interface, where all information such as volume, orientation and opening sizes and orientation must be entered in regarding the space. AIOLOS produces statistical results which calculate the amount of air moving through a space and the duration it takes for air changes within multi-room buildings. Yet, because it does not use virtual models, it is not able to illustrate the flow, such as possible with more complex programs – something that could further benefit the designer.

AIOLOS is able to calculate global airflow rates within rooms, airflow rates through each of the openings, and the pressure coefficient on exterior surfaces. In addition this tool offers the designer many simulation possibilities which can either be used for design purposes or simply be exploited to provide a deeper insight of the mechanisms involved in natural ventilation. Such simulations allow for the derivation of the appropriate sizes for openings which will achieve optimum airflow rates in the investigated configurations. Likewise, the 'sensitivity' analysis allows for the investigation of the impact of specific parameters on natural ventilation. And lastly as a thermal model it assesses the impact of various natural ventilation strategies on the thermal behaviour of the building.

These calculations can be run for as little as a day or for an extended time period up to one year. Climatic data can be treated statistically through an inbuilt climatic pre-processor. This feature gives the user the option of a quick assessment of the prevailing climatic characteristics in the region the building is located in.

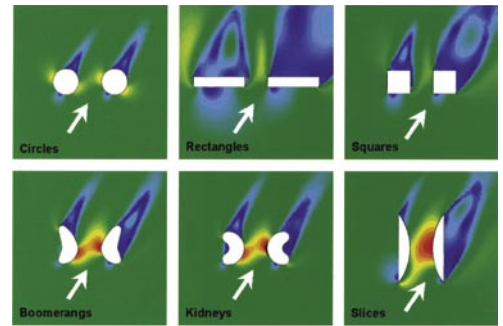


fig. E.17 - Example of CFD velocity plots for twin tower buildings used for examining wind enhancements for Project WEB research.

- Red Areas - good wind enhancements
- Blue Areas - separation of flow and re-circulation patterns
- Green Areas - free stream or atmosphere conditions

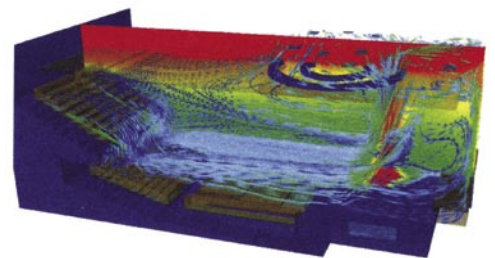


fig. E.18 - CFD model for the auditorium design used in developing the Experimental Media and Performing Arts Center at the Rensselaer Polytechnic Institute in Troy, New York by Nicholas Grimshaw and Partners.



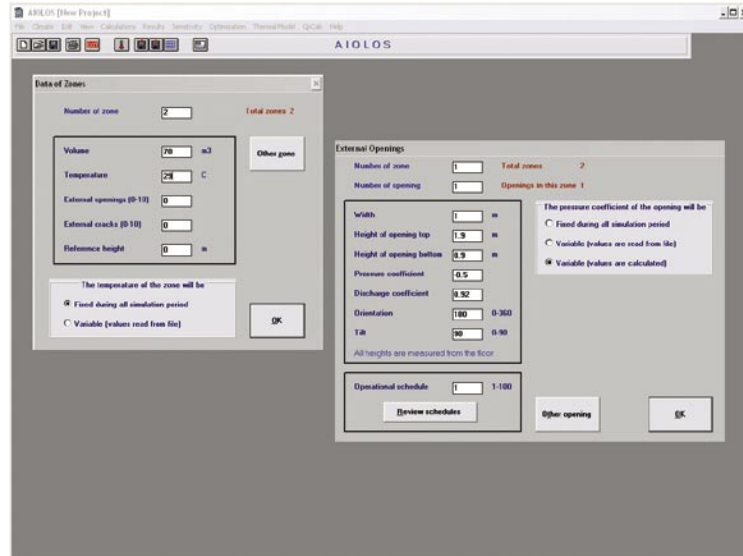


fig. E.19 - The AIOLOS interface used for inputting design data.

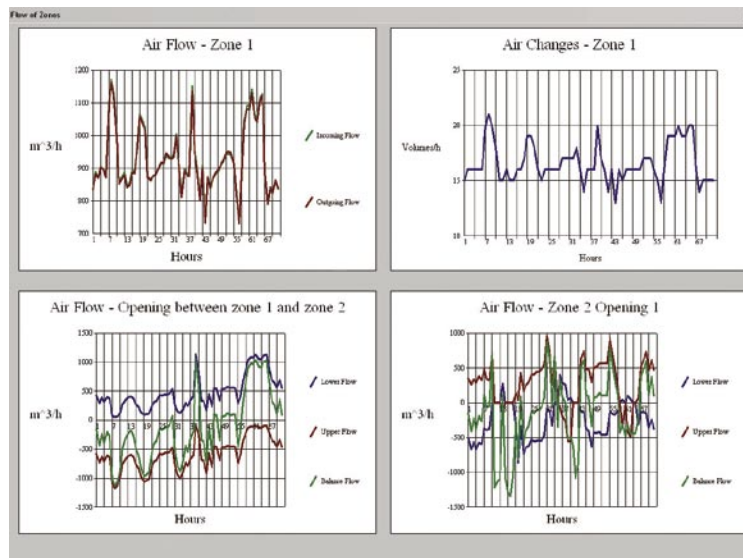


fig. E.20 - Examples of AIOLOS output for 'zone' or room flow rates.

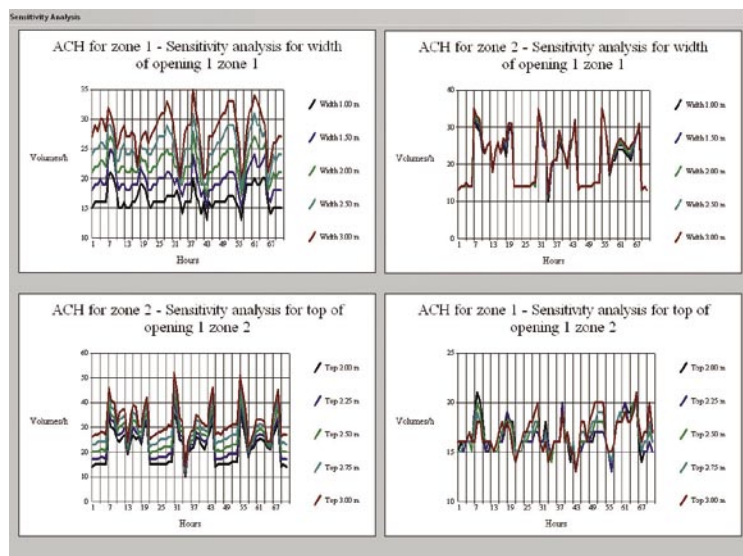


fig. E.21 - Examples of AIOLOS sensitivity output for investigating appropriate sizes for optimum design.

See fig. E.19 – E.21 for image and graph examples from AIOLOS and the calculations that the program produces.

AIOLOS is a good introductory program for design students and for those new to CFD's. It presents a good starting point for design projects and is most useful for simplified architectural design. Although AIOLOS is straightforward, it tends to be cumbersome at the outset especially for someone with little to no experience. There is a required learning curve before the program can be used efficiently to its full extent. AIOLOS' greatest feature is its ability to test a single parameter at a time, to determine minimum and maximum values for width or height sizes of openings. This enables the designer to find the best solution for the air movement strategy. Unfortunately, because of its simplistic nature it can not be used to in multifaceted, complex designs. Its greatest shortcoming is its preset base of site and weather information that is currently limited to a handful of locations. This makes the program time-consuming and cumbersome in more universal applications.

#### CFD and the Designer

The simplistic programs which are available to architectural designers can help develop and plan the design before it is finalized and/or sent to a specialist. Designers are able to provide calculations of their design performance, giving some idea of the validity of the design. The greatest feat of CFD for architectural design is to provide information about *internal* air flow. Scale models are not very useful to examine the interior workings of a space, because they have to be done in pieces and at a relatively large scale in order to be of any use. Doing all tests in a virtual model alleviates this restriction and opens up the possibilities of what and how much can be tested. Furthermore, CFD has the ability to add temperature values of materials and fluids to the calculation, which is very difficult to simulate in the scale models.

Over the years of their development, these programs have advanced from providing statistical results to now producing complete virtual models with illustrations of the fluidic motion. Designers are now able to get more than just a quantitative value of movement as we now have the ability to demonstrate the behaviour of that quantity of air.

It should be noted, as with all simulation software, that the simulation can only predict what it has been programmed to, and therefore cannot produce anything unique that may

present itself in scale model testing. This is something that the designer should keep in mind when using computer assisted programs.

## E.4

## Specialists

The progression of the designer's work with air movement leads the thesis to inquire as to what else is available, beyond the scope of the designer's own capabilities.

### Overview

In the case of more involved design projects, designers may need to go beyond their own means and seek out some specialized services. Or as a design nears completion, a specialist may be needed to confirm or refine the proposed design. Specialists have tools not readily available to the designer as well as collections of information not easily accessible – such as weather behaviour for certain sites. As the importance of buildings and their air movement (internally and externally) has developed, specialists have come from the field of mechanical engineering, specifically working in fluid dynamics. The services that they provide revolve around wind tunnel testing, water flume testing, and computer modeling with advanced computational fluid dynamics (CFD – as mentioned above). Scientists and engineers have been studying fluid dynamics for years, and have many ways of testing the motion of fluid; these include jet streaming air over an object, blowing metallic crystals into the air, injecting dyes or sands into streams of water, and most recently the use of 3D computer models and calculations. These processes prove to be effective ways of measuring and visualizing fluid motion. The position of the specialist is to either confirm or refute what the designer has proposed, and may then proceed to develop solutions to resolve and fulfil the designer's intentions. Specialists' abilities and tools can be wheeled by the designer to accomplish attentive architecture.

### Specialist: RWDI

When the site conditions are major factors in the development of a project, the designer can seek out the specialist to ease the process. A world class example of such a specialist is Rowan Williams Davis and Irwin Inc. (RWDI) in Guelph, Ontario. They are one of the leading wind engineering consulting services firm in the world. As such, the company offers a complete



fig. E.22 - One of two wind tunnels at the Guelph office of Rowan Williams Davies and Irwin Inc.

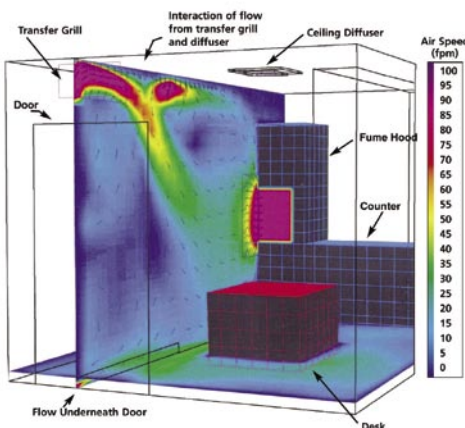


fig. E.23 - Air velocities over two planes for a laboratory calculated using CFD at RWDI.



fig. E.24 - Site model completed at RWDI's model shop on an 8 foot turntable to be tested in their wind tunnel for pressure tests.

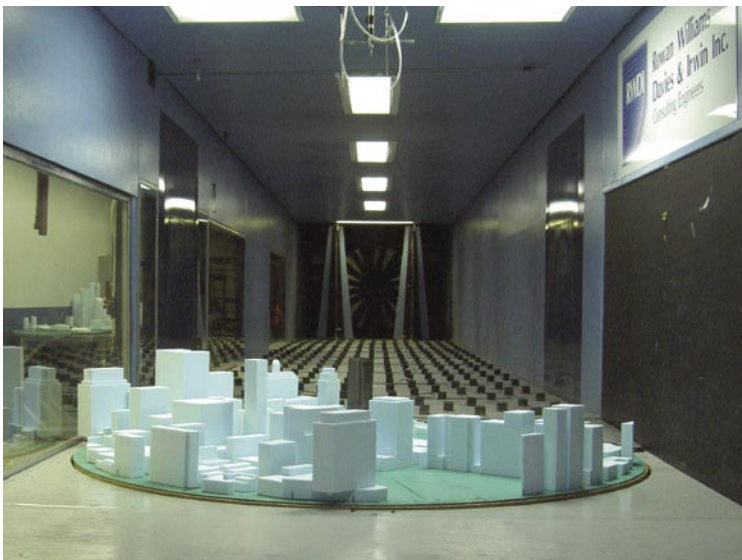


fig. E.25 - Site model placed inside RWDI's boundary layer wind tunnel used to simulate and measure wind characteristics and exhaust gas dispersion patterns.

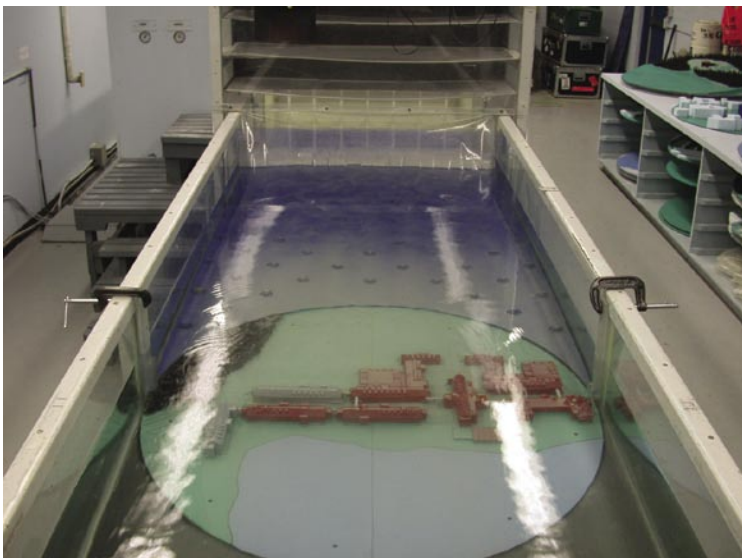


fig. E.26 - Example of RWDI's water flume equipment used to test snow accumulation, wind patterns, wind flows and emission paths on and around buildings.





fig. E.27 - Underside of a building model showing all the tubed connections which are used to read the pressures occurring on the model while testing in the wind tunnel.

range of wind engineering, environmental air quality and noise management services. RWDI has offices around the globe to reach beyond their regional client base.<sup>3</sup> During the thesis preparation, a facility tour was taken of RWDI's office in Guelph. See fig. E.23 - E.27 for photographs which illustrate some of the tools specialists offer.

The firm's facilities include two boundary layer wind tunnels, an open channel water flume, and advanced computer modeling capabilities including computational fluid dynamics (CFD). The staff is a comprehensive blend of senior scientists, engineers, specialists, meteorologists, engineering technologists and modellers, technicians and support staff. The firm's key clients include leading architectural, mechanical and structural engineering firms, as well as private and public facility owners. To accomplish their specialist role they also have an in-house model shop that uses stereo-lithography technology, integrated data acquisition, storage and processing systems, computer-aided drafting, and a broad base of specialized instrumentation.<sup>4</sup>

### Specialists and the Designer

Wind-tunnel tests using scale models are far more reliable than simply knowing generalized patterns; unfortunately, such tests are expensive and still not perfect. Nevertheless, a site can and should be analyzed realistically for seasonal and annual wind utilization. Neighbouring buildings create local anomalies in wind flow that make extensive wind-tunnel testing advisable before constructing any tall building. This is done to determine the full structural loads that must be resisted by the skin and skeleton of the building, as well as any ground-level wind problems that could trouble pedestrians and drivers. Most important to those concerned with air dynamics, wind tunnel testing determines wind loading information for wind suctions or pressures at building intakes, exhausts, and at openings such as windows and doorways. All of which is valuable information for the development of air movements within the enclosure.

The specialist also offers advanced CFD modeling and computation. As mentioned earlier, the CFD field of study allows the specialist to have good insight into the workings of air movement within an enclosure. Only recently realized CFD adds to the external tools previously available for wind tunnel and water flume tests. Being well versed with the tool of CFD, the specialist will be able to quickly create and simulate the designer's enclosure to understand the internal reactions. Specialists are able to provide very complex processes which



are not readily accessible to most designers, or for that matter, classroom environments. Again the information that the specialist can offer the designer is priceless in pre-determining the reality of the project before construction.

## Endnotes

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- <sup>1</sup> With the approval of the thesis advisor, Professor Terri Meyer Boake, three undergraduate students collaborated on the smoke box exercise for the duration of the fall 2006 term in exchange for credit. The undergraduate students who participated were Sue Chen, Krista Duynisveld and Tyler Walker. The development led to the first classroom trial in the following winter of 2006 and has continued to be used by Professor Terri Meyer Boake
- <sup>2</sup> Nathalie Hamill, "Streamlining Fluid Dynamics," Mechanical Engineering Magazine Online, <http://www.memagazine.org/backissues/march98/features/stream/stream.html> (5 June 2006).
- <sup>3</sup> Rowan Williams Davies & Irwin, "RWDI (RWDI AIR) Wind Engineering / Environmental Consultant: Overview," <http://www.rwdi.com/default.aspx> (24 June 2006).
- <sup>4</sup> *ibid.*



## Bibliography

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- "Swiss Re [London]." *Architects' Journal* 219, no. 15 (Apr, 2004): 64-66.
- "Beyond the Individual Building." *Architectural Record* 140, no. 3 (Sept, 1966): 161-172.
- "Scarborough College, Ontario." *Canadian Architect* 11, (May, 1966): 41-62.
- Allen, Edward. *How Buildings Work : The Natural Order of Architecture*. 2nd ed. New York: Oxford University Press, 1995.
- Allen, Edward and Joseph Iano. *The Architect's Studio Companion : Rules of Thumb for Preliminary Design*. 2nd ed. New York: Wiley, 1995.
- Atif, Morad. "Top Glazed Public Spaces: Amenities, Energy Costs and Indoor Environment." *Construction Canada* 36, no. 1 (1994): 43-47.
- Banham, Reyner. *Architecture of the Well-Tempered Environment*. 2nd ed. Chicago: University of Chicago Press, 1984.
- Battle McCarthy Consulting Engineers. *Wind Towers*. Detail in Building. Chichester, West Sussex: Academy Editions, 1999.
- Bednar, Michael J. *The New Atrium*. McGraw-Hill Building Types Series. New York: McGraw-Hill, 1986.
- Binggeli, Corky. *Building Systems for Interior Designers*. Hoboken, N.J.: J. Wiley & Sons, 2003.
- Boutet, Terry S. *Controlling Air Movement : A Manual for Architects and Builders*. New York ; Montreal: McGraw-Hill, 1987.
- Boyd, David R. *Canada Vs. the OECD : An Environmental Comparison*. Victoria, B.C.: University of Victoria, Eco-Research Chair of Environmental Law & Policy, 2001.
- Brown, G. Z. and Mark DeKay. *Sun, Wind & Light : Architectural Design Strategies*. 2nd ed. New York ; Chichester England: John Wiley, 2001.
- Camesasca, Ettore. *History of the House. with a Foreword by Sir Robert Matthew. Translated by Isabel Quigly*. 1st American ed. New York: Putnam, 1971.
- Campbell, N. S. and eds Stankovic. "Wind Energy for the Built Environment: Project WEB." (2001).
- Carter, Brian. "Practical Experiment: Science and Technology Centre, Toronto, Canada." *The Architectural Review* 216, no. 1292 (Oct, 2004): 72-75.

- Chodikoff, Ian. "Vital Organ." *Canadian Architect* 49, no. 2 (FEB, 2004): 16-19.
- Compagno, Andrea. "Innovative Hochhausfassaden: Swiss Re Konzernzentrale Und Westhafen-Tower = Innovative Tower Block Facades: Swiss Re London Headquarters and Westhafen Tower, Frankfurt = Grattacieli, Swiss Re + Westhafen = Facades De Tours Innovantes: Siège De La Swiss Re Et Westhafen-Power = Nuevas Pielas Para Rascacielos: Swiss Re y Westhafen Tower." *Detail* 43, no. 7-8 (July-Aug, 2003): 820-826.
- Coonley, Douglas R. *Design with Wind*. Harrisville, N.H: Total Environmental Action, 1974.
- Czarnecki, John E. "Without Architectural Fanfare, Busby + Associates and architectsAlliance Demonstrate Sustainability in a Northern Climate with York University's Computer Science Building." *Architectural Record* 191, no. 2 (Feb, 2003): 138-145.
- Davies, Colin and Ian Lambot. *Commerzbank Frankfurt: Prototype of an Ecological High-Rise = Modell Eines Ökologischen Hochhauses*. Combin English and German ed. Haselmere, Surrey, UK; Boston: Watermark ;\$aBasel; Birkhäuser, 1997.
- Daws, L. F. *Movement of Air Streams Indoors* 1967.
- Daws, L. F., A. D. Penwarden, and G. T. Waters. *Visualization Technique for the Study of Air Movement in Rooms* 1965.
- Devereux, Julien and Martin C. Pedersen. "How Buildings Breathe: A Savvy Mix of High Technology and Age-Old Wisdom is Delivering Healthier Air to Indoor Spaces from Office Complexes to Concert Halls." *Metropolis* 23, no. 7 (Mar, 2004): 102-105.
- Ferrara, Luigi, Emily Visser, Teresa Meyer Boake, Ian Chodikoff, Peter Busby, and Toronto and Region Conservation Authority. *Canada Innovates: Sustainable Building*. Canada Innovates. Vol. 2. Toronto: School of Design, George Brown College, 2006.
- Fleming, John, Hugh Honour, and Nikolaus Pevsner. *The Penguin Dictionary of Architecture*. Penguin Reference Books. 4th ed. Harmondsworth: Penguin, 1991.
- Foster, Norman, Chris Abel, and David Jenkins. *Norman Foster : Works*. Munich ; London: Prestel, 2002.
- G.H. Brundtland (Chair) and World Commission on Environment and Development. *Our Common Future*. Oxford: Oxford University Press, 1987.
- Ghiaus, Cristian and Francis Allard. *Natural Ventilation in the Urban Environment : Assessment and Design*. Buildings, Energy, Solar Technology. London: Earthscan, 2005.

- Government of Canada: Statistics Canada. *2003 Survey of Household Energy use (SHEU) : Detailed Statistical Report*. Ottawa: Office of Energy Efficiency, 2005.
- . "Report on Energy Supply-Demand in Canada 2003 = Bulletin Sur La Disponibilité Et Écoulement d'Énergie Au Canada 2003." (2004).
- Gregory, Rob. "Squaring the Circle: 30 St. Mary Axe, London." *The Architectural Review* 215, no. 1287 (May, 2004): 80-85.
- Groat, Linda N. and David Wang. *Architectural Research Methods*. New York: J. Wiley, 2002.
- Guzowski, Mary. *Daylighting for Sustainable Design*. McGraw-Hill Professional Architecture. New York ; London: McGraw-Hill, 2000.
- Harrison, Douglas and Brian Johnston. *User's Guide for the Ontario Building Code*. Toronto: Carswell, 1990.
- Hix, John. *The Glass House*. London: Phaidon, 1974.
- Janssen, John E. "The History of Ventilation and Temperature Control." *ASHRAE Journal* 41, no. 10 (October, 1999): 48+.
- Jen, Leslie. "Green Machine." *Canadian Architect* 50, no. 1 (JAN, 2005): 16-18.
- Jen, Leslie. "Genetic Complement: Terrence Donnelly Centre for Cellular and Biomolecular Research, Toronto, Ontario: Architectsalliance and Behnisch, Behnisch & Parnmer." *Canadian Architect* 51, no. 1 (Jan, 2006): 28-33.
- Kadulski, Richard. *Residential Ventilation : Achieving Indoor Air Quality*. North Vancouver, BC: Drawing-Room Graphic Services, 1988.
- Kapusta, Beth. "Learning from History." *Azure Magazine* (March-April, 2005): 96-101.
- KPMB Architects. *Centennial College Science and Technology Centre - Project Brief Press Release*.
- Larkin, David and Bruce Brooks Pfeiffer. *Frank Lloyd Wright : The Masterworks*. New York: Rizzoli in association with the Frank Lloyd Wright Foundation, 1993.
- Lechner, Norbert. *Heating, Cooling, Lighting : Design Methods for Architects*. 2nd ed. New York ; Chichester England: John Wiley, 2001.
- Levine, Neil and Frank Lloyd Wright. *The Architecture of Frank Lloyd Wright*. Princeton, N.J.: Princeton University Press, 1996.
- Macaulay, David R. and Jason F. McLennan. *The Ecological Engineer*. Kansas, MO: Ecotone Publishing, 2006.
- McMinn, John. "Code Green." *Canadian Architect* 47, no. 1 (JAN, 2002): 18-21.



- . "Sustained Discussion." *Canadian Architect* 46, no. 1 (JAN, 2001): 13-19.
- Moore, Fuller. *Environmental Control Systems: Heating, Cooling, Lighting*. New York ; Toronto: McGraw-Hill, 1993.
- Norberg-Schulz, Christian. *The Concept of Dwelling : On the Way to Figurative Architecture*. Architectural Documents. Milan; New York: Electa; Rizzoli, 1985.
- . *Meaning in Western Architecture* [Significato nell'architettura occidentale. English]. New York: Praeger, 1975.
- Ontario. Housing Development and Buildings Branch. *Ontario Building Code 1997 : Containing the Building Code Act Reg. 40397*. Toronto: Ministry of Municipal Affairs and Housing, Housing Development and Buildings Branch, 1997.
- Pagani, Freda. "Green Buildings are Still Rare." *The Georgia Straight*, 3 November, 2005, sec. Commentary.
- Polo, Marco. "Green Giant." *Canadian Architect* 48, no. 1 (JAN, 2003): 20-25.
- Randell, John Edward. *Ambient Energy and Building Design*. Lancaster, Eng. ; New York: Construction Press, 1978.
- Russell, James S. "In a City Averse to Towers, 30 St. Mary Axe, the "Towering Innuendo" by Foster and Partners, is a Big Ecofriendly Hit." *Architectural Record* 192, no. 6 (June, 2004): 218-227.
- Santamouris, M., Francis Allard, European Commission. Directorate-General for Energy, and ALTENER Programme. *Natural Ventilation in Buildings : A Design Handbook*. London: James and James Science Publishers Ltd., 1998.
- Saxon, Richard. *The Atrium Comes of Age*. Harlow, Essex, England: Longman, 1994.
- . *Atrium Buildings : Development and Design*. London: The Architectural Press, 1983.
- St. John Wilson, Colin. *The Other Tradition of Modern Architecture : The Uncompleted Project*. London: Black Dog Publishing, 2007.
- Stein, Benjamin. *Mechanical and Electrical Equipment for Buildings*. 10th ed. Hoboken, N.J.: Wiley, 2006.
- Stein, Benjamin and John Reynolds. *Mechanical and Electrical Equipment for Buildings*. 9th ed. New York ; Chichester England: Wiley, 2000.
- Taylor, Jennifer and John Andrews. *John Andrews: Architecture, a Performing Art*. New York: Oxford University Press, 1982.
- Treiber, Daniel. *Norman Foster*. Architecture Collection. English language ed. London: Spon, 1995.

- Van Dyke, Milton D. *An Album of Fluid Motion*. Stanford, Calif.: Parabolic Press, 1982.
- Visualization Society of Japan. *Atlas of Visualization*. Progress in Visualization. 1st ed. Vol. 1. Oxford ; New York: Pergamon Press, 1993.
- Vitruvius Pollio and Morris Hicky Morgan. *Vitruvius : The Ten Books on Architecture*. New York: Dover Publications, 1960.
- Willims, Austin and Susan Dawson. "Round Peg in a Square Hole [Swiss Re, London]." *Architects' Journal* 216, no. 11 (Sept, 2002): 26-35.
- Wright, Ronald. *A Short History of Progress*. 1st Carroll & Graf ed. New York; Berkeley, Calif.: Carroll & Graf Publishers; Distributed by Publishers Group West, 2005.
- Wyman, Morrill. *A Practical Treatise on Ventilation*. Boston; London: J. Munroe & Co.; Chapman Brothers, 1846.

## Web Resources

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- AIVC - Air Infiltration and Ventilation Centre. "How does Ventilation Work?" <http://www.aivc.org/frameset/frameset.html?./Faq/faq2.html~mainFrame> (18 December, 2006).
- Answers.com. "Atrium: Definition, Synonyms and Much More." <http://www.answers.com/topic/atrium?cat=biz-fin> (14 December, 2006).
- architectsAlliance. "Portfolio." <http://www.architectsalliance.com/portfolio> (18 October, 2006).
- ArchitectureWeek. "Environment - Cool and Green - 2002.0403." [http://www.architectureweek.com/2002/0403/environment\\_1-1.html](http://www.architectureweek.com/2002/0403/environment_1-1.html) (17 August, 2006).
- BEHNISCH ARCHITEKTEN. "Sustainability - Terrence Donnelly Centre for Cellular and Biomolecular Research." <http://www.behnisch.com/> (19 September, 2006).
- BuildingGreen.com. "EBN 14:3 - Green Globes Emerges to Challenge LEED." <http://www.buildinggreen.com/auth/article.cfm?fileName=140304b.xml> (26 September, 2006).
- Canada Green Building Council. "MEC Montreal - GBC2005 Canada." [http://greenbuilding.ca/iisbe/gbc2k5/teams/canada/MEC/can\\_MEC.htm](http://greenbuilding.ca/iisbe/gbc2k5/teams/canada/MEC/can_MEC.htm) (18 April, 2006).
- CS&P Architects Inc. "Projects - Academic - Georgian College." <http://www.csparch.com/> (20 October, 2006).
- Foster + Partners. "Projects - Health/Education - Leslie L. Dan Pharmacy Building." <http://www.fosterandpartners.com/Projects/1183/Default.aspx> (24 September, 2006).

- Government of Canada: Natural Resources Canada. "Commercial and Institutional Consumption of Energy Survey (CICES)." <http://oee.nrcan.gc.ca/Publications/statistics/cices05/section1.cfm?attr=0> (23 November, 2006).
- Government of Ontario: Ministry of Finance. "Building Ontario's Future A Superbuild Progress Report." <http://www.fin.gov.on.ca/english/budget/bud01/papere.html> (24 November, 2006).
- GreenBiz. "Sustainability in Architecture and Design: An Interview with Bert Gregory." [http://www.greenbiz.com/news/reviews\\_third.cfm?NewsID=26732](http://www.greenbiz.com/news/reviews_third.cfm?NewsID=26732) (2 December, 2006).
- Hamill, Nathalie. "Streamlining Fluid Dynamics." Mechanical Engineering Magazine Online. <http://www.memagazine.org/backissues/march98/features/stream/stream.html> (5 June, 2006).
- KPMB Architects. "Projects - Centennial HP Science and Technology Centre." <http://www.kpmbarchitects.com/index.asp?navid=30&fid1=48&fid2=10&fid3=32&minyearx=&maxyearx=> (27 June, 2006).
- Levitt Goodman Architects. "Projects - Educational - School of Architecture U of W." <http://levittgoodmanarchitects.com/project?p=uwsa&c1=educational&c2=None> (21 July, 2006).
- Office of Energy Efficiency, Natural Resources Canada. *Energy Innovators- Sir Sanford Fleming College: On the Leading Edge of Energy Management* Natural Resources Canada, October 2001, <http://oee.nrcan.gc.ca/publications/infosource/pub/ici/eij/m27-01-1600e.cfm?attr=20> (5 October, 2004).
- Organization for Economic Cooperation and Development. "OECD: Energy Consumption." <http://www.environmentalindicators.com/htdocs/indicators/8ener.htm> (3 December, 2006).
- PhysicalGeography.net and Fundamentals of Physical Geography. "7(n) Forces Acting to Create Wind - Chapter 7." <http://www.physicalgeography.net/fundamentals/7n.html> (20 July, 2006).
- Read Jones Christoffersen. "What we do - HP Centennial College, Science and Technology Centre." <http://www.rjc.ca/cms/page1653.cfm> (27 June, 2006).
- Rowan Williams Davies & Irwin. "RWDI (RWDI AIR) Wind Engineering / Environmental Consultant: Overview." <http://www.rwdi.com/default.aspx> (24 June, 2006).
- Schaffner, Christopher R. "The Green Engineer - Displacement Ventilation." <http://www.greenengineer.com/ideas/dv.htm> (18 December, 2006).

- Smith and Andersen Consulting Engineering. "Projects - Educational - Post Secondary." <http://www.smithandandersen.com/ProjectDetails.asp?ProjIndex=5> (17 November, 2006).
- Storm Prediction Center, National Oceanic and Atmospheric Association. "Beaufort Wind Scale." <http://www.spc.noaa.gov/faq/tornado/beaufort.html> (16 October, 2006).
- Tamblyn, R. T. and Advanced Building Technologies and Practices. "Ventilation & Air Quality - Displacement Ventilation." [http://www.advancedbuildings.org/main\\_t\\_vent\\_displ\\_vent.htm](http://www.advancedbuildings.org/main_t_vent_displ_vent.htm) (18 December, 2006).
- The Columbia Electronic Encyclopedia, Sixth Edition, Columbia University Press., 2003. "Atrium." <http://www.answers.com/topic/atrium?cat=biz-fin#copyright> (25 October, 2006).
- The Weather Doctor. "Weather Elements: Sea and Land Breezes." <http://www.islandnet.com/~see/weather/elements/seabrz.htm> (18 July, 2006).
- University of Nebraska Omaha. "Cartography and Geographic Information Systems Laboratory - Wind Principles." <http://maps.unomaha.edu/Peake/3510/windprinciples.htm> (18 July, 2006).
- University of Strathclyde. "ESRU Home Page - Institute for Energy and Environment - Ventilation." <http://www.esru.strath.ac.uk/> (18 December, 2006).
- University of Waterloo School of Architecture. "A New Home for the School." <http://www.architecture.uwaterloo.ca/cambridge/index.html> (21 July, 2006).
- Weekly Dose of Architecture. "Centennial HP Science and Technology Centre." <http://www.archidose.org/Feb06/022706.html> (10 February, 2006).
- Whole Building Design Guide. "WBDG: Optimize Energy use." [http://wbdg.org/design/minimize\\_consumption.php](http://wbdg.org/design/minimize_consumption.php) (7 December, 2006).
- Wikipedia contributors. "Atrium (Architecture)." Wikipedia, The Free Encyclopedia. [http://en.wikipedia.org/wiki/atrium\\_\(architecture\)?oldid=159862031](http://en.wikipedia.org/wiki/atrium_(architecture)?oldid=159862031) (17 July, 2006).
- . "World Population." Wikipedia, The Free Encyclopedia. [http://en.wikipedia.org/wiki/world\\_population](http://en.wikipedia.org/wiki/world_population) (19 July, 2006).
- World Health Organization. "Housing and Health Regulations in Europe - Final Report July 2006." <http://www.euro.who.int/document/e89278.pdf> (18 August, 2006).

---

## Resources for Survey Information

- Algonquin College. "Algonquin College." <http://www.algonquincollege.com> (20 September, 2006).
- Amer, Bashar. *Phone Conversation with B. Amer Director of Facilities Management, George Brown College*. 26 October 2006.
- Archon Architect Inc. "Archon Architect- Portfolio." <http://www.archonarchitect.com/> (25 September, 2006).
- aTRM Architects. "Selected Portfolio - Academic." [http://www.atrm.on.ca/academic\\_01.html](http://www.atrm.on.ca/academic_01.html) (17 October, 2006).
- Baker, Harry. *E-Mail Exchange with H. Baker Director Facilities Planning and Development, Fanshawe College* 1 November 2006.
- Barry J. Hobin & Associates Architects. "Projects- Educational." <http://www.hobinarc.com/education/index.html> (21 November, 2006).
- BBB Architects. "Our Portfolio - Institutional." <http://www.bbb.ca/> (5 November, 2006).
- Bregman + Hamann Architects. "Architecture - Portfolio - Institutional - Queen's University- Beamish Munro Hall." <http://www.bharchitects.com/architecture/portfolio/institution-queens.htm> (8 November, 2006).
- Brock University. "Major Projects - Plaza Building Facilities Management Brock University." [http://www.brocku.ca/facilitiesmgmt/CON\\_MAJOR\\_PLZ.htm](http://www.brocku.ca/facilitiesmgmt/CON_MAJOR_PLZ.htm) (9 May, 2006).
- Canadian Architect - Daily News. "Friday, January 23, 2004 - TEL Building." [http://www.cdnarchitect.com/issues/ISarticle.asp?id=26547&story\\_id=&issue=01232004&PC=&btac=no](http://www.cdnarchitect.com/issues/ISarticle.asp?id=26547&story_id=&issue=01232004&PC=&btac=no) (11 October, 2006).
- Cannon Design. "Expertise - Project Catalog - Leslie L. Dan Pharmacy Building- University of Toronto." <http://cannondesign.com/> (19 October, 2006).
- Carleton University. "Physical Plant- Construction- Major Capital Projects." <http://www.carleton.ca/physicalplant/construction/capital.htm> (15 October, 2006).
- Caruso, Adam. "Schulich School of Business, Toronto, Ontario: Hariri Pontarini Architects and Robbie-Young + Wright Architects." *Canadian Architect* 51, no. 5 (May, 2006): 50-51.
- Caulfeild, Pat. *E-Mail Exchange with P. Caulfeild, Director of Construction, Physical Plant Services, Queen's University*. 25 October 2006.



- Chamberlain - Architecture Construction Management. "Portfolio - Learning." [http://www.chamberlain-online.com/portfolio\\_learning.htm](http://www.chamberlain-online.com/portfolio_learning.htm) (7 October, 2006).
- Cianfrone Architect. "Institutional Architecture." [http://www.cianfronearchitect.com/institutional\\_architecture.shtml](http://www.cianfronearchitect.com/institutional_architecture.shtml) (18 October, 2006).
- Cole+Associates Architects. "Portfolio." <http://www.cole.on.ca/portfolio/port1.htm> (accessed 10 November, 2006).
- Conestoga College. "New Construction on Campus." <http://www.conestogac.on.ca/jsp/news/2001/20010730.jsp> (10 October, 2006).
- Cote, Raymonde. *Phone Conversation with R. Cote, Assistant to the Director, Physical Resources Service, University of Ottawa.*2006.
- Diamond + Schmitt Architects Inc. "Projects." <http://www.dsai.ca/> (17 November, 2006).
- Dupuis, Ron. *E-Mail Exchange with R. Dupuis, Physical Resources Assistant Vice President, Wilfrid Laurier University.*2006.
- Edward J Cuhaci and Associates Architects Inc. "Projects." <http://www.cuhaci.com/projects.html> (27 October, 2006).
- Griffiths Rankin Cook Architects. "Portfolio - Completed Work." <http://www.grcarchitects.com/portfolio.htm> (12 November, 2006).
- Hamilton, Ian. *Phone Conversation with I. Hamilton, Director of Campus Planning and Facilities, Ryerson University.*27 October 2006.
- Hariri Pontarini Architects. "Menu - Projects - Academic." <http://www.hariripontarini.com/> (23 October, 2006).
- Hart, Sara. "With His First Commission in North America, Will Alsop Boldly Takes to the Air at Ontario College of Art and Design's Sharp Centre in Toronto." *Architectural Record* 192, no. 8 (Aug, 2004): 124-127.
- Humber College. "Humber College." <http://www.humber.ca> (22 September, 2006).
- IKOY. "Projects - School of Information Technology and Engineering (SITE)." <http://www.ikoy.com/> (24 September, 2006).
- LaBrie, John. *Phone Conversation with J. LaBrie Director of Physical Resources, Georgian College.*26 October 2006.
- LeMay, Dennis. *E-Mail Exchange with D. LeMay, Project Administration Manager, Physical Plant, University of Western Ontario.*2006.
- LINE Architect Inc. "Sustainability." <http://www.linearchitect.com/> (16 September, 2006).
- Mackay-Lyons Sweetapple Architects Ltd. "Projects." <http://www.mlsarchitects.ca/> (19 September, 2006).

- Mackey, Blayne. *Phone Conversation with B. Mackey, Executive Director, Physical Resources, St. Lawrence College.* 27 October 2006.
- McMann, Gary. *E-Mail Exchange with G. McMann, Senior Manager, Facility Planning, Design and Construction, University of Windsor.* 2006.
- McMaster University. "Physical Plant - Construction." <http://www.mcmaster.ca/ua/opr/construction/abb.htm> (27 September, 2006).
- MJM Architects. "Projects - Institutional - University of Waterloo CECS Building." <http://www.mjmachitects.com/> (15 November, 2006).
- Mohawk College. "2004 Community Report- Campus Renewal and Expansion." [http://www.mohawkcollege.ca/mcinfofr/CommunityReports/2004\\_2005/expansion.html](http://www.mohawkcollege.ca/mcinfofr/CommunityReports/2004_2005/expansion.html) (12 November, 2006).
- Montgomery Sisam. "Portfolio - Education - Arts and Administration Building, University of Toronto." <http://www.montgomerysisam.com/> (9 November, 2006).
- Moriyama & Teshima Architects. "Projects - University." <http://www.mtarch.com/mtaprojects.html> (23 September, 2006).
- Niagra College. "Niagra College." <http://www.niagrac.on.ca/> (2 November, 2006).
- NORR Limited. "Education." <http://www.norrlimited.com/education.asp> (7 November, 2006).
- Ontario College of Art and Design. "Ontario College of Art and Design." <http://www.ocad.on.ca> (1 November, 2006).
- Phillips, Rhys. "Plugged-in SITE: School of Information Technology and Engineering, University of Ottawa, Ottawa, Ontario - IKOY Architects Ltd." *Canadian Architect* 48, no. 7 (July, 2003): 22-27.
- Pickard, Chris. *Phone Conversation with C. Pickard, Director of Design, Engineering and Construction, Physical Resources, University of Guelph.* 2006.
- Queen's Quay Architects International Inc. "Portfolio - Public Facility - Ryerson University School of Business." <http://www.q2a.net/framesets/portfolio.html> (23 October, 2006).
- RHL Architects Toronto. "Projects/ Experience - Post Secondary Projects." <http://www.rhlarch.com/postsecondary.asp> (16 September, 2006).
- Robbie Sane Architects. "Projects - Sir Sanford Fleming." <http://www.rsarch.ca/> (6 November, 2006).

- Robbie/Young + Wright Architects Inc. "Projects." [http://www.rywarch.ca/newsite/ryw\\_content.html](http://www.rywarch.ca/newsite/ryw_content.html) (12 October, 2006).
- Rounthwaite Dick and Hadley Architects Inc. "Education - Continuing Education Building, Ryerson Univesity." [http://www.rdharch.com/education/continuing\\_education\\_ryerson/](http://www.rdharch.com/education/continuing_education_ryerson/) (10 November, 2006).
- saucier + perrotte architectes. "Communication, Culture and Technology Building." <http://www.saucierperrotte.com/> (15 September, 2006).
- Seneca College. "Seneca College." <http://www.senecac.on.ca/cms/> (28 September, 2006).
- Sheridan College. "Sheridan College." <http://www1.sheridaninstitute.ca> (18 September, 2006).
- Shore Tilbe Irwin and Partners. "Projects - Educational." <http://www.stipartners.com/> (13 October, 2006).
- St. Clair College. "St. Clair College." <http://www.stclaricollege.ca/> (16 October, 2006).
- Stone McQuire Vogt Architects. "Projects - Educational Projects - Centennial College of Applied Arts and Technology." [http://smvarch.com/projects/d/ei\\_centennial\\_college\\_applied\\_of\\_arts\\_and\\_technology.html](http://smvarch.com/projects/d/ei_centennial_college_applied_of_arts_and_technology.html) (21 November, 2006).
- Taylor and Hazell Architects Ltd. "Index of Projects - Computer Technology Centre." <http://www.taylorhazell.com/> (18 October, 2006).
- Tayona, Nova. "Plane Geometry." *Canadian Architect* 51, no. 11 (NOV, 2006): 48-53.
- Teeple Architects Inc. "Portfolio - Educational." <http://www.teeplearch.com/> (4 November, 2006).
- The Ventin Group Architects. "Queen's University School of Business." [http://www.ventingroup.com/univer\\_3.html](http://www.ventingroup.com/univer_3.html) (18 September, 2006).
- The Walter Fedy Partnership. "Projects - Post Secondary - Conestoga College Institute of Technology and Advanced Learning." [http://www.twfp.com/en/projects/edu\\_conestoga.asp](http://www.twfp.com/en/projects/edu_conestoga.asp) (19 October, 2006).
- Two Row Architect. "Trent University - First Peoples House of Learning." <http://www.tworow.com/pdfs/TrentU.pdf> (12 November, 2006).
- University of Ontario Institute of Technology. "University of Ontario Institute of Technology." <http://www.uoit.ca/> (20 September, 2006).
- University of Toronto. "Capital Projects." <http://www.greatspaces.utoronto.ca/> (4 November, 2006).

WASYLKO ARCHITECT Inc. "Projects - Institutional." <http://www.warchs.com/Projects%20institutional.htm> (20 November, 2006).

York University. "Facilities Services." <http://www.yorku.ca/facilities/facilitiesdevelopment/index.html> (5 November, 2006).

Zeidler Partnership Architects. "Projects." <http://www.zeidlerpartnership.com/to/frameset/mainframeset.htm> (17 October, 2006).